Pioneers of Science and Discovery

Rudolf Diesel

and the Diesel Engine

John F Moon

Diesel engines play a part in everyone's life. They generate electricity; they pump water and gas; they propel ships, trucks and buses; they power railway locomotives and all types of earthmoving and construction machinery; they are the mechanical life of the farmer. In other words, it is hard to use anything in the home, or to travel anywhere, without the diesel engine playing its part.

RUDOLF DIESEL was a fascinating man. He was a practical genius whose ideas were, to begin with, too revolutionary for more than a few farsighted engineers to try out. With success in 1897, he became a rich man—but he was not to enjoy his fame and riches to the full. With ruinous property deals draining his fortune, and worsening headaches and gout, he became desperate and in 1913 committed suicide.

John Moon tells the story of this remarkable man and shows the problems so often besetting a brilliant inventor ahead of his time. He has used a minimum of technical language, essential terms being carefully explained in the text and in a full glossary. The book contains more than fifty illustrations, a date chart, reading list and index.

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Rudolf Christian Karl Diesel
(1858–1913)

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European Editor, *"Diesel & Gas Turbine Progress Worldwide"*

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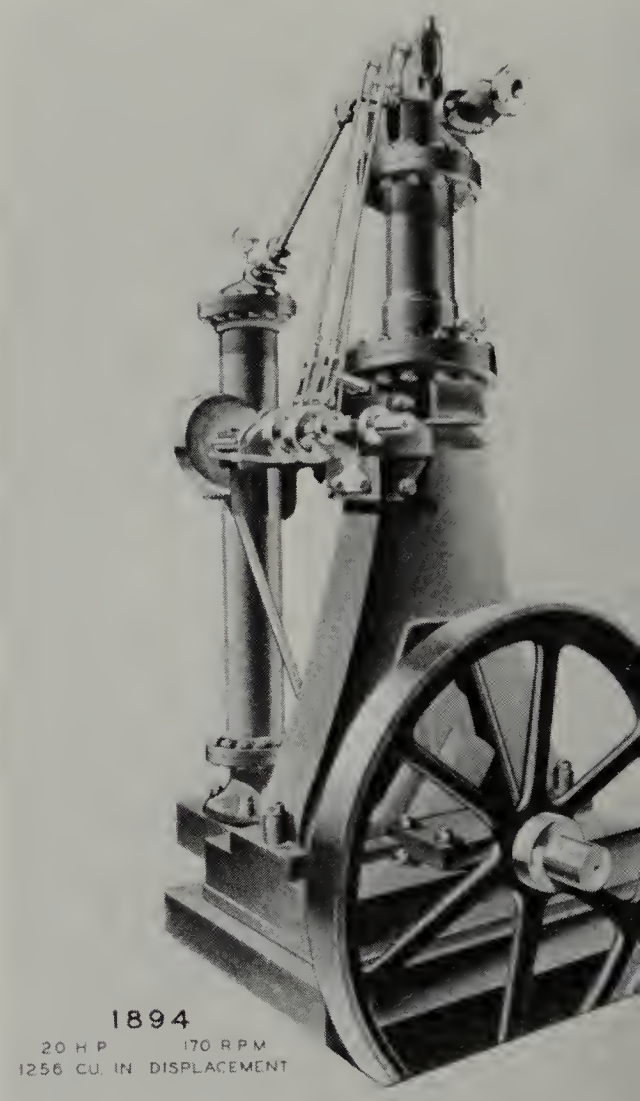
Introduction

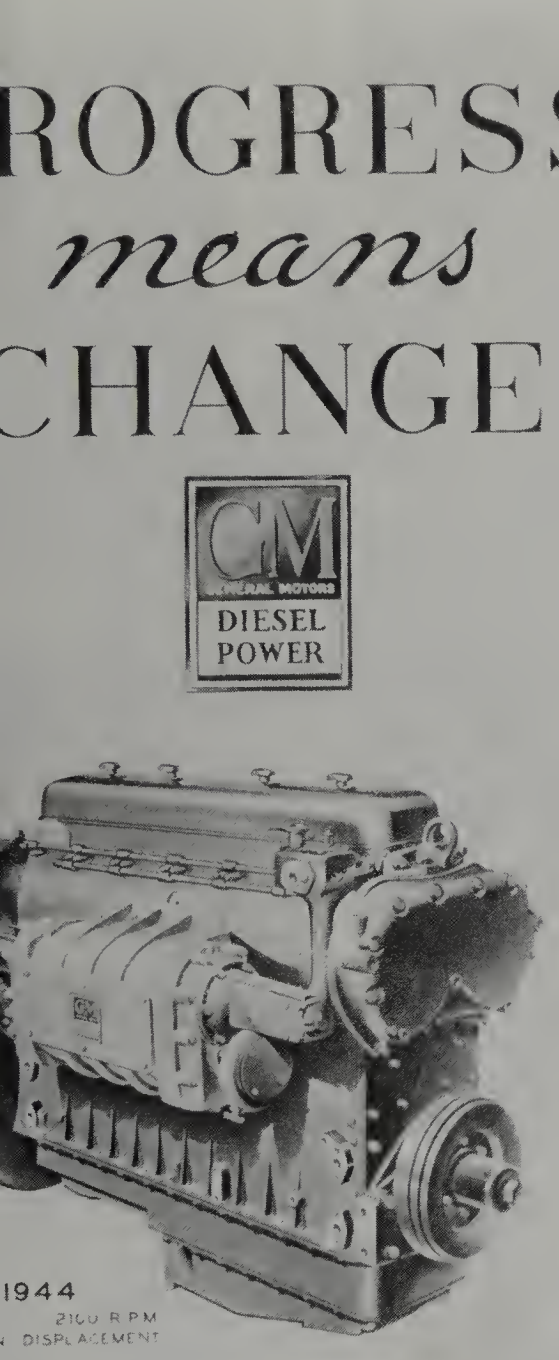
Rarely does an inventor's name become universally accepted as the name of that same inventor's brainchild. There is nothing about the motor car, radio, television, aircraft, gas turbines or many other inventions that nowadays form an everyday part of our lives to suggest which person or persons was responsible for their conception. In many cases, this is because such inventions were not the work of a single man, but came about as the result of successive developments by a series of people.

Nevertheless, we tend to think of Benz and Daimler as having evolved the first practical motor cars, Marconi as having fathered radio, Baird as having shown that television was possible, the Wright brothers as being the first to fly in a heavier-than-air machine, Whittle as being a principal pioneer of the gas-turbine engine, and so forth, but we only know these names through having read of them.

One name that has been handed down to us with the invention itself, however, is that of Diesel, whose sparkless compression-ignition engine—evolved at the end of the nineteenth century—is still the world's most widely used industrial form of power because Rudolf Diesel's original concept of obtaining the maximum amount of work from a given heat source has yet to be bettered commercially.

Diesel engines play some part in the lives of everybody these days. They generate electricity; they pump water and gas; they propel ships, trucks and buses; they power railway locomotives and all types of earthmoving and construction machinery; they are the mechanical life of the farmer. In other words, it is difficult to use anything in the home or to travel anywhere without the diesel engine playing its part.





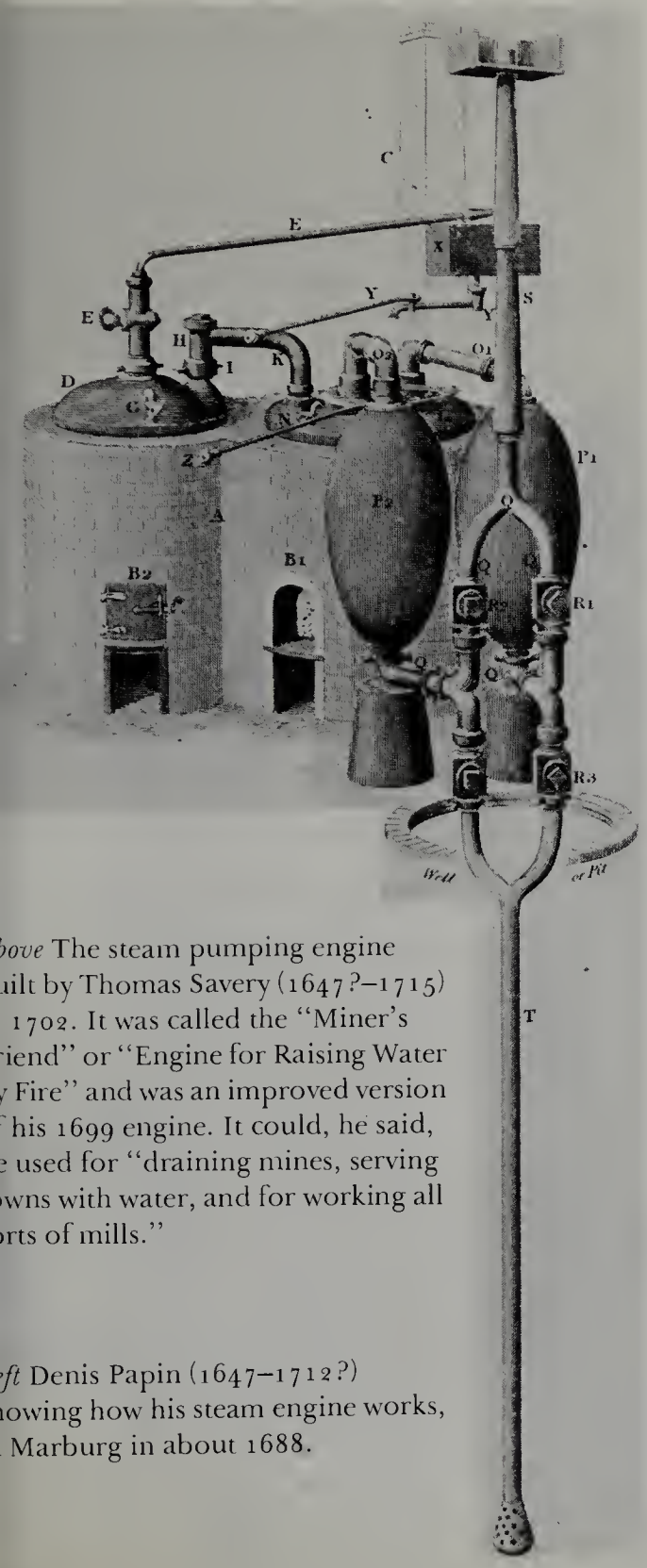
The diesel engine has its competitors and its critics, of course. The petrol engine continues to be virtually the only form of power for cars, the gas turbine ("jet" engine) is used exclusively for all but the lightest types of aircraft, and steam turbines continue to power very large ships and generate most of our electricity. Similarly, land and marine diesels are being challenged by the industrial and marine types of gas turbine where high powers are required in the most compact form possible, although it can never be envisaged that the gas turbine will ever replace more than a small percentage of diesel engines.

But the evolution of the diesel engine has by no means finished, and over the years it has become steadily more efficient and more adaptable, with the result that its usage is increasing all the time. It is just possible that in a hundred years' time there may be no more diesel engines in use, in the same way as the piston-type steam engine has virtually disappeared from the scene after a life span of over 250 years which started with Thomas Newcomen's engine of 1712. But one thing is certain, and that is that Diesel's name will not be forgotten for hundreds of years—if ever.

A 1944 advertisement showing fifty years progress of diesel engines. On the left is Diesel's prototype which was built and tested in 1893—not 1894 as in the advertisement, though it was rebuilt and retested in 1894 and 1895. On the right is the "latest" General Motors model.

ft Hero demonstrating his aeolipile
his colleagues in Alexandria.

1 *The Road to the Internal Combustion Engine*



bove The steam pumping engine
uilt by Thomas Savery (1647?–1715)
1702. It was called the "Miner's
riend" or "Engine for Raising Water
y Fire" and was an improved version
f his 1699 engine. It could, he said,
e used for "draining mines, serving
wns with water, and for working all
rts of mills."

ft Denis Papin (1647–1712?)
nowing how his steam engine works,
Marburg in about 1688.

For over two thousand years, man has sought to harness the energy contained in heat. The ancient Greek philosophers dreamed of dispensing with the need for muscle power, and these dreams were partially realized when Hero of Alexandria built a "jet propelled" machine consisting of a metal sphere with tangentially arranged open tubes around it. However, Hero's machine, which was called an "aeolipile," had little practical use.

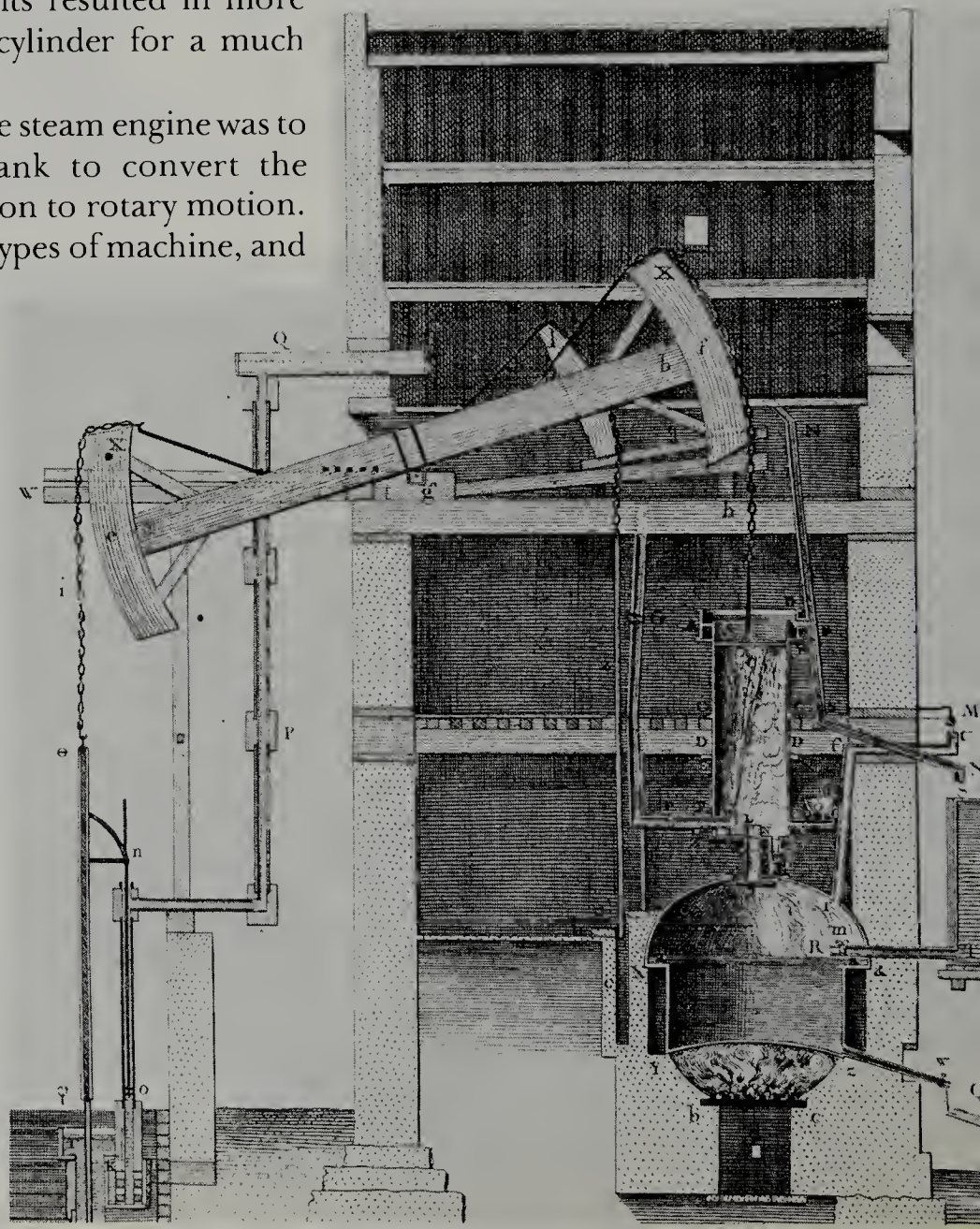
The first important step towards a working engine was made in 1688 by the Frenchman Denis Papin, who used steam as the driving force to move a piston outwards within a cylinder, the steam then being cooled so that it condensed and created a reduced pressure behind the piston, so causing atmospheric pressure to force it back into the cylinder. Papin's "engine" failed because he could not manufacture it satisfactorily with the crude tools available at that time, but it had been proposed that his machine should be used to pump water out of mines with greater effectiveness than the water or muscle power then in use.

However, a principle was established, and this was taken up in England at the turn of the century when the Cornishman Thomas Savery built a steam pumping engine which worked on similar "atmospheric" principles to the Papin engine. This in turn attracted the attention of another Englishman, Thomas Newcomen, a Dartmouth blacksmith. He made a model of the Papin engine and then went on to improve on it. In this new engine the steam was provided by a separate boiler instead of being produced inside the cylinder itself. Newcomen's first commercial water-pumping engine was built in 1712, and its use spread

rapidly to mines throughout Great Britain. It was also used for water supply purposes in some areas.

The Newcomen engine, however, still had the disadvantage of excessively high fuel consumption. This point was not lost on the Scotsman James Watt, who saw that there was considerable room for improvement. His first step was to develop a condenser for the steam, placing it outside the cylinder. This meant that heat did not have to be wasted each cycle in heating up the cylinder again. He then hit upon the idea of making the steam drive the piston both up and down the cylinder, thereby dispensing with the original "atmospheric" principle of the Papin and Newcomen engines. These two developments resulted in more power being obtained from a cylinder for a much lower rate of fuel consumption.

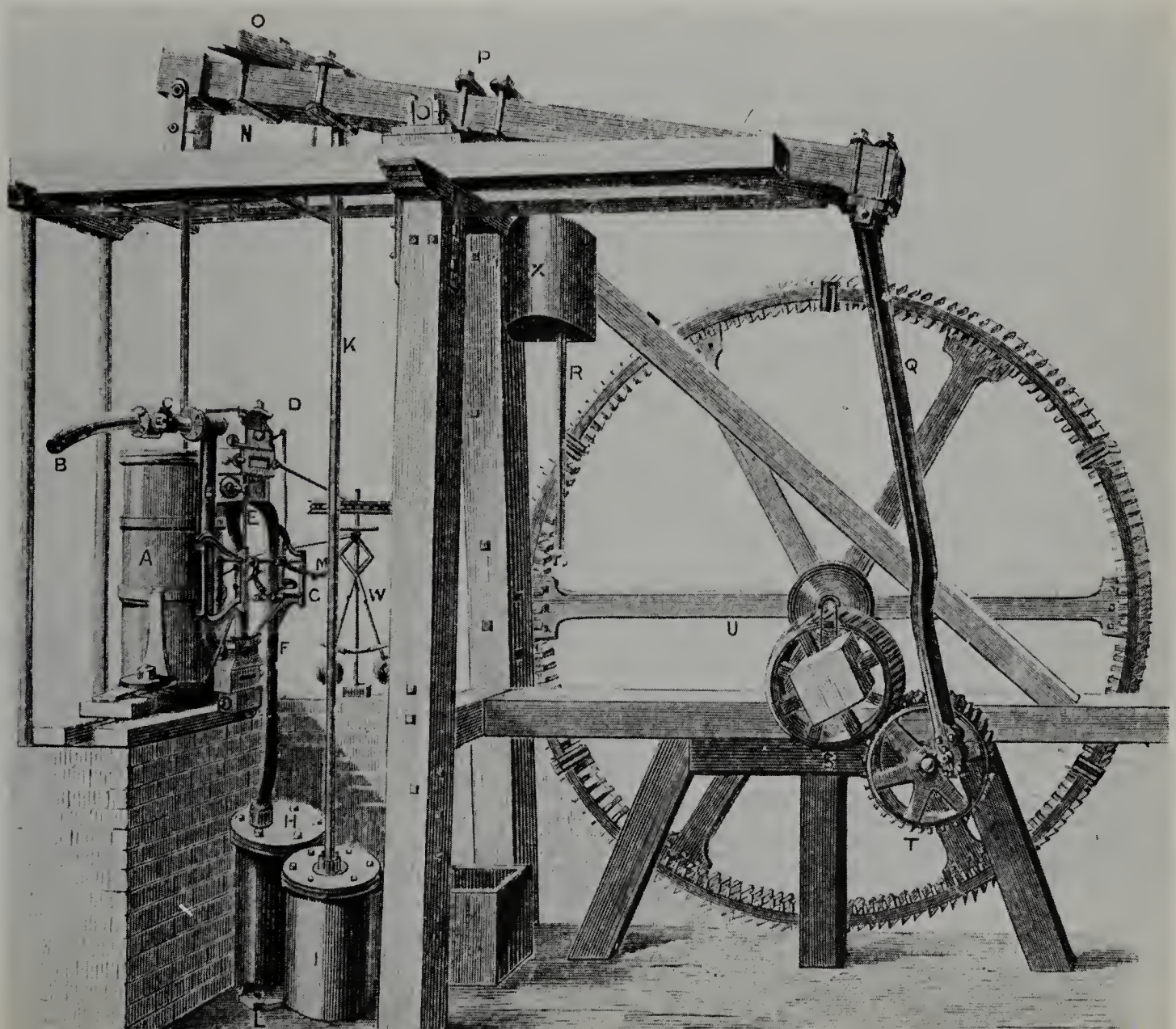
Watt's final contribution to the steam engine was to use a connected rod and crank to convert the reciprocating motion of the piston to rotary motion. The engine could now drive all types of machine, and



This engine, probably built in France, was based on Thomas Newcomen's idea of producing the steam for steam engines in a separate boiler instead of inside the cylinder itself.

was no longer confined to pumping duties. James Watt's engine was undoubtedly a success, and he soon went into partnership with the Birmingham industrialist, Matthew Boulton, to form the world famous steam engine manufacturing concern, Boulton & Watt, which by the end of the eighteenth century had built hundreds of the Watt-type low-pressure steam engine.

The Watt engine in turn attracted the attention of Richard Trevithick, a Cornishman, and he built a high-pressure version of the engine which he used to power the world's first railway locomotive. In February, 1804, this hauled a load weighing twenty



"Old Bess," James Watt's prototype steam engine built in 1774. The reciprocating motion of the piston is turned into rotary motion by a "sun-and-planet" arrangement of gears.

tons at five miles an hour (eight kilometres per hour) on a tramway at the Pen-y-darren ironworks near Merthyr Tydfyl, in South Wales.

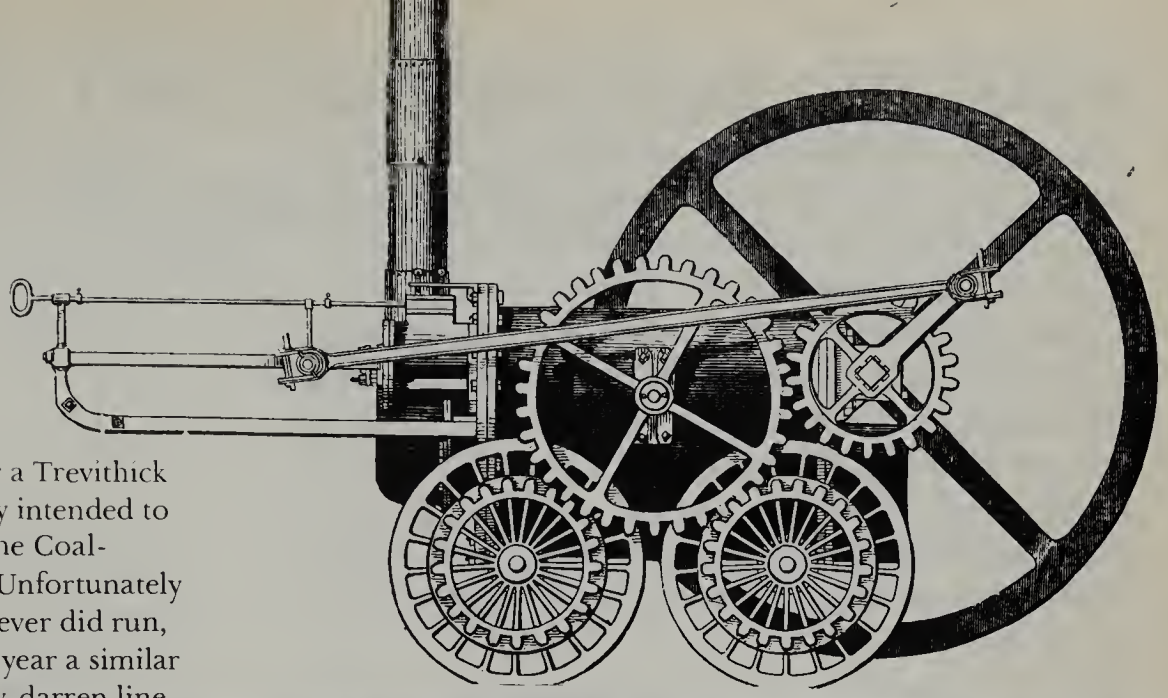
This Trevithick locomotive was not the first wheeled machine to move under steam power, however, because the Frenchman, Nicholas Joseph Cugnot, built a model steam-engined three wheeled gun carriage in 1765, followed by a full sized artillery tractor in 1770, although this proved too dangerous to use on public roads. It had no brakes!

So the steam engine started to take its place as man's slave, and it went through rapid phases of development until at one time it looked as though it was going to prove the ultimate in power. Vast steamships were built to hasten hundreds of passengers across the high seas in comfort and—usually—safety, and by 1845 regular railway services in Britain were achieving maximum speeds of over sixty miles per hour (ninety-six kilometres per hour).

The average steam engine of those days, however, was large and heavy, and although more efficient than any other form of power then available, it used coal greedily. By the mid-1800s engineers were turning their attention to other and smaller possible types of engine. The most likely answer to the fuel problem appeared to be that of using gas and exploding it inside the cylinder to drive a piston down the cylinder as the exploded gas expanded. This involved "internal" combustion, as opposed to the steam engine's "external" combustion, but even so the gas engine still got its fuel from coal—in the form of coal gas—and coal was thought to be the only practicable source of heat for engines at the time.

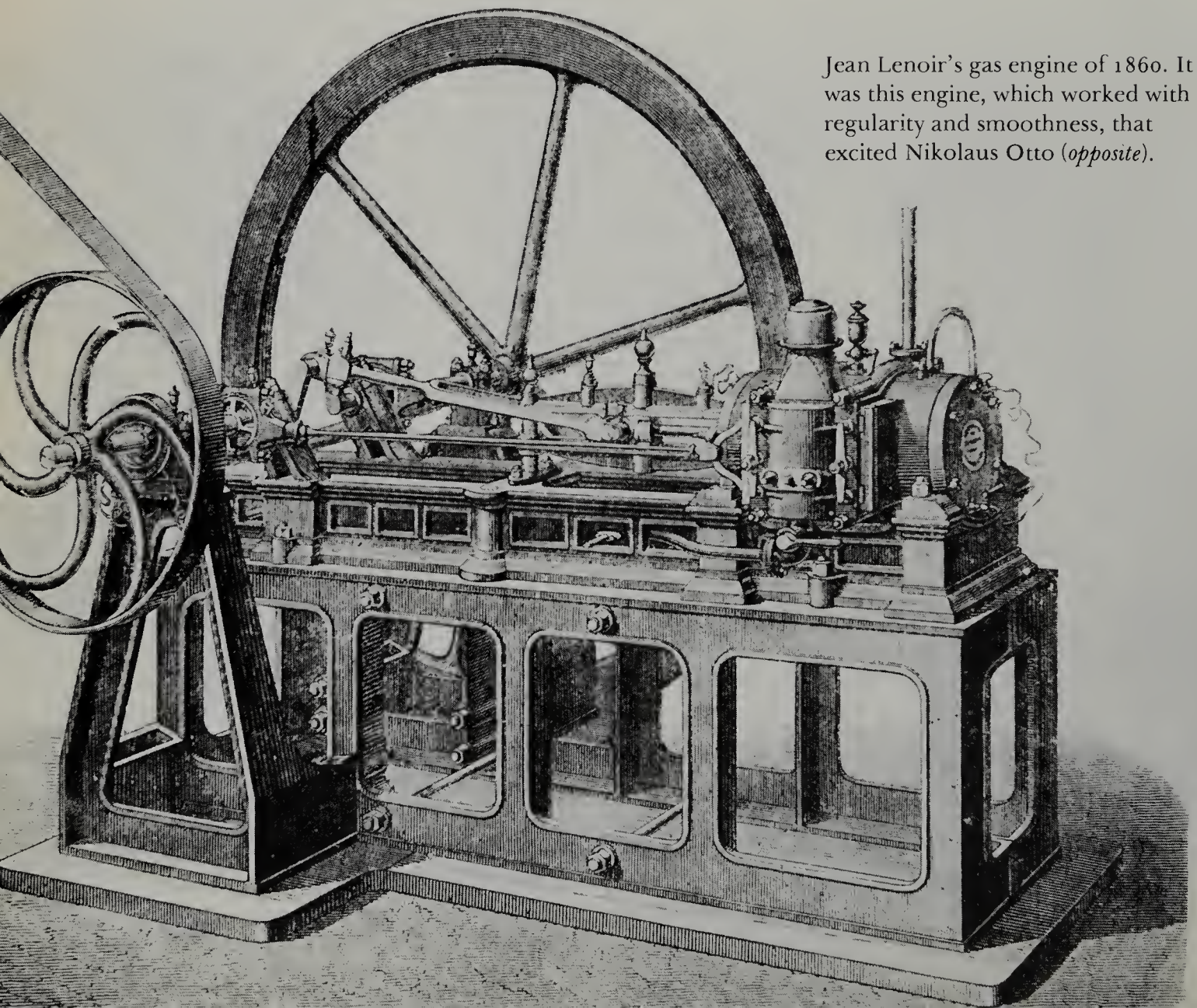
The use of gas as an engine fuel was first put forward publicly by a Frenchman, Phillipe Lebon d'Humbersin, in 1801, but it was not until 1860 that the modern internal combustion engine started to take shape as the result of work done by another

The steam-driven artillery tractor built by Nicholas Joseph Cugnot (1725–1804) in 1770. It was difficult to control, top heavy, lacked good steam pressure and had a maximum speed of four miles an hour.



Right An 1803 design for a Trevithick railway engine, probably intended to run on the tramway at the Coalbrookdale Iron Works. Unfortunately there is no proof that it ever did run, though in the following year a similar engine did, on the Pen-y-darren line.

Frenchman, Jean Joseph Etienne Lenoir, who took out a patent that year for a gas engine which took in a charge of gas/air mixture during one portion of the piston's stroke, which was then ignited by an electric spark at a later stage of the engine's cycle. Lenoir's engine is recorded as having worked very quietly and to have been easy to start, whilst its efficiency was three times that of contemporary steam engines. These engines were of comparatively low power, but several hundred of them were made in both France and England, and Lenoir himself fitted one into a carriage which he ran on French roads.



Jean Lenoir's gas engine of 1860. It was this engine, which worked with regularity and smoothness, that excited Nikolaus Otto (*opposite*).

2 *The Compression-Ignition Engine Arrives*

Nikolaus August Otto (1832–1891) patented the four stroke cycle in Germany in 1876 even though the principle had already been formulated in 1862 by Alphonse Beau de Rochas, a Frenchman, of whose work Otto apparently knew nothing.

Lenoir's engine looked—and worked—like a double-acting steam engine in that the gas/air mixture was alternately exploded on both sides of the piston. The Lenoir engine was such an advance over other forms of gas engine that engineers from all over Europe rushed to study it, meanwhile ignoring the work being done at the same time by a French railway engineer, Alphonse Beau de Rochas. De Rochas was the first person to put forward the theory of the "four stroke" cycle for internal combustion engines, and his paper, published in 1862, included references to an ultra-high-compression engine which would have self-ignition—a foretaste on paper of the true compression–ignition engine.

De Rochas was not interested in the four stroke cycle as such. His aim had been to give increased engine efficiency by getting the highest possible pressure inside the cylinder before ignition took place, and also by reducing heat losses to the cooling water around the cylinder. But de Rochas' four stroke cycle was to point the way for most internal combustion engines since made.

De Rochas has never received the credit he deserves for this cycle, all the honour having gone to the German Nikolaus August Otto, who independently developed a four stroke engine at about the same time with the object of improving upon the Lenoir type of engine. Otto's first trial four stroke gas engine ran in Cologne, Germany, at the beginning of 1862, but it would not run smoothly. So in 1864 Otto entered into partnership with another engineer, Eugen Langen, to form the world's first internal combustion engine factory, the eventual product being an atmospheric type of gas engine which was conclusively shown to be

much more economical in gas usage than any Lenoir-type engine. The four stroke cycle had to wait for some years, however, though it was never far from Otto's thoughts.

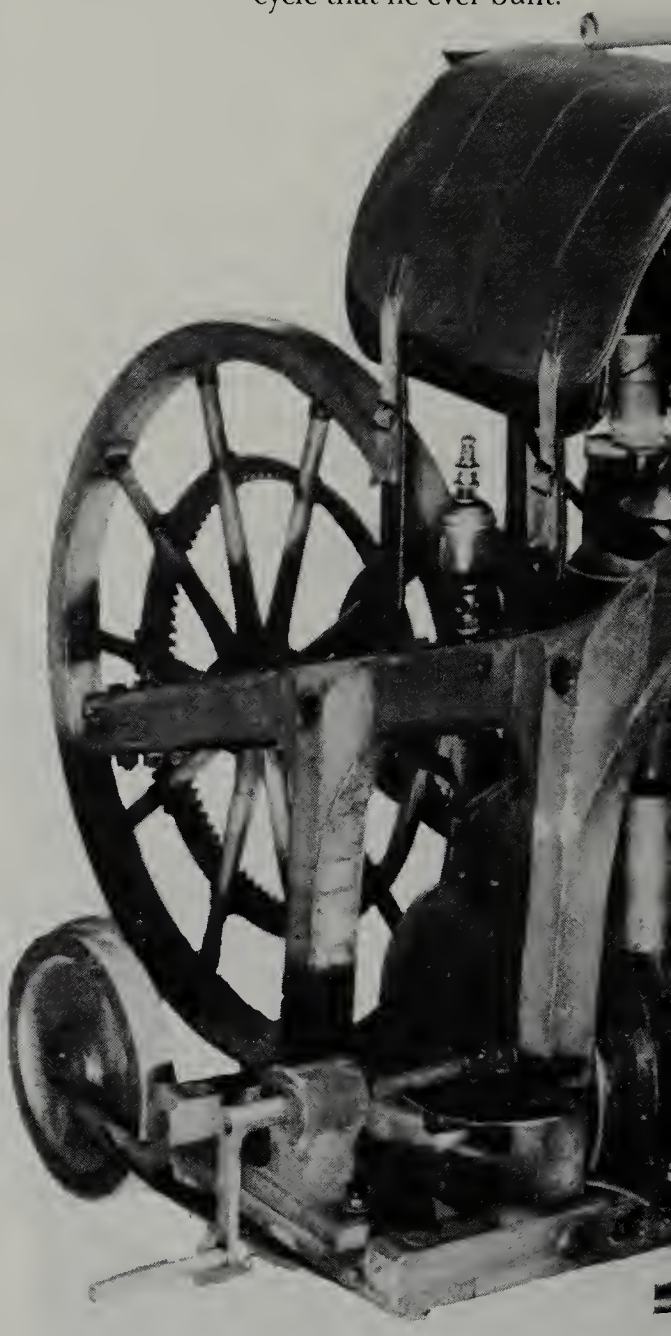
The Otto plant was moved to a new site at Deutz in 1869, where Deutz diesel engines are still made by the Klöcker-Humboldt-Deutz concern, and in the same year a licence was granted to the British Crossley company. Although somewhat noisy, the Otto atmospheric gas engine was a great success, partly because of its reliability, and several thousand were sold all over Europe, and even to America. But Otto was keen to produce an engine that did not run on gas, and therefore was not tied to a gas pipe.

In other words, he wanted an engine that could operate independently and carry its own fuel around with it. Lenoir had managed this in 1862 with his gas-engined carriage, but the gas had to be carried in a tank, which gave a very restricted range of operation. Two years later, in 1864, the Austrian, Siegfried Markus, of Mecklenburg, carried out a similar experiment. This, vehicle, however, had even less range than the Lenoir carriage, though in 1875 Markus made a more successful self-propelled machine that ran for considerable distances.

In the meantime, Otto had been working on the idea of a high-compression engine which would have slow-burning combustion characteristics to give smoother running, and to achieve this he returned to his original 1862 principle of the four stroke cycle. An experimental engine ran early in 1876, and this can be called the father of the modern internal combustion engine, even though it still ran on gas. Production of the original atmospheric-type engines was virtually stopped once the new design had been proved, and during the next years over eight thousand four stroke gas engines were made at the Deutz factory.

In 1877, Otto started work on an experimental petrol-burning version of his four stroke engine,

Gottlieb Daimler (1834–1900) built, in 1885, a motorcycle framed with wood and iron with a half-horse power petrol engine mounted centrally. It was, in fact, the only motorcycle that he ever built.



primarily for use at sea, and that had the same crude type of carburettor as had been developed some years earlier for a petrol version of Otto's atmospheric gas engine. The main difference here was that gas-flame ignition could not be used, and although attempts were made to employ an electric spark, the first engines made use of a glowing platinum point to fire the petrol/air mixture in the cylinder. Later, a low voltage electric ignition system, the forerunner of the present spark ignition used in modern petrol engines, was adopted — the same idea that had been tried out in Italy about twenty years earlier.

Otto temporarily dropped work on the petrol engine, partly because he had to spend so much time in courts defending his patents, but in 1884 he started again and perfected the magneto ignition principle, and the following year Deutz displayed a successful four stroke, spark-ignition petrol engine at the Antwerp World's Fair.

But he was not the first. Two Germans who had both worked with Otto for many years had produced a small, lightweight high speed petrol engine—albeit with hot-tube ignition—in 1883. These men were Wilhelm Maybach, who was latter to achieve distinction in the diesel field, and Gottlieb Daimler, who applied the new engine to a motor cycle in 1885 and to a four wheeled motor carriage in 1886. Also in Germany, Karl Benz had patented a small two stroke gas engine in 1882, and by 1885 he had developed from this a petrol engine with his own design of spark ignition. One year later, Benz put this engine in a three wheeled car.

The success of these liquid fuel engines, together with work done by other engineers, such as the Americans Brayton (in 1873) and Regan (in 1883), led to a surge in demand for small petrol engines for road vehicles, boats and machinery, and this in turn did more than anything else to hasten the search for oil fields in various parts of the world.

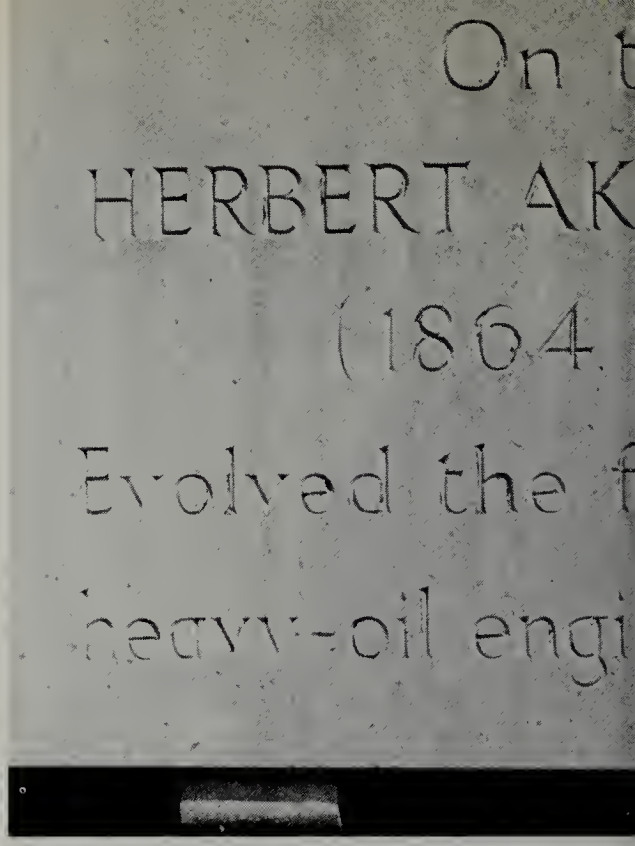
But the gas engine was by no means dead yet, and it filled the need for industrial power between the high-power steam engine and the low-power petrol engine, holding its own quite successfully against the small, medium-power steam engines that were being developed in the meantime.

Although more convenient to use than steam engines, the gas engines of the day were still fairly expensive to operate and were, of course, still dependent on the local town's gas supply for their fuel. Engineers, therefore, turned to developing liquid fuel engines other than those burning petrol. The production of petrol from crude oil involves a fractionating process in which heavier types of oil, such as kerosene and gas oil, are also produced, and these oils can be produced more cheaply than the most highly refined petrols.

So here, provided these heavier oils could be made to burn inside an engine, was a cheaper fuel source. It seemed to some engineers that the best way to manage this would be to vaporize the oil before trying to ignite it, and several engines of this type were produced in Europe and the United States of America during the 1870s and 1880s. These had a vaporizing chamber on the cylinder head which was heated by an external flame and into which the fuel was injected before ignition by spark. Even Otto had thought of this type of engine before he died on 26th January, 1891, but he never put his ideas into practice.

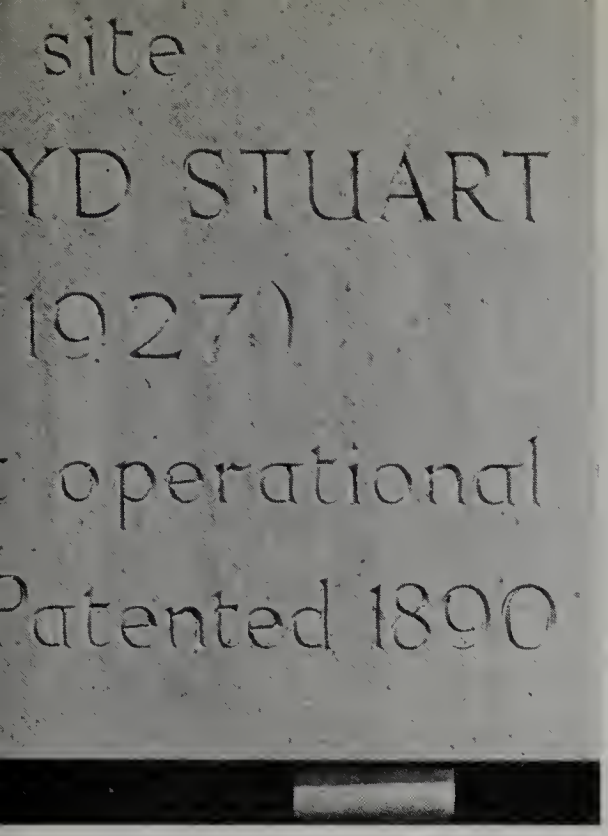
These engines with vaporizing chambers were known as "hot-bulb" engines because of the need to keep the chamber heated. The need for an external heat source was an obvious disadvantage. The first really successful engine of this type was developed in England in 1885 by the Priestman brothers, who managed to get round this problem by keeping the bulb at the correct high temperature by the engine's own exhaust gases once the engine had been started.

The Priestman engine was instantly recognized as a



Above The plaque on the wall of the Bletchley and District Cooperative Society shop in Fenny Stratford where Akroyd Stuart's workshops were located.

Right Herbert Akroyd Stuart (1864–1927) who invented an oil engine in 1890 which some people believe to have been the true start of diesel engine production. It was certainly the world's first "compression-ignition" engine.



big step forward, but in the meantime a Yorkshire engineer by name of Herbert Akroyd Stuart had also been working on the idea of an "oil" engine, and in 1890 he and a colleague, Charles Richard Binney, took out two patents covering the admission of air into the vaporizer and the timed point of injection. Stuart started to build engines along these lines at a little factory in Bletchley, Buckinghamshire, and many people believe that this was the true start of diesel engine production because the Stuart engine did not rely on an external heat source or an electric spark to ignite the fuel. Burning was achieved by injecting the fuel into the highly compressed air in the vaporizer chamber, above the cylinder head, at the end of the compression stroke, this compressed air being at a high enough temperature to heat the walls of the chamber to be above the ignition temperature of the fuel. So here was the world's first "compression-ignition" engine.

Stuart's engine was of the four stroke type, and it had a combustion chamber and vaporizer "bulb" at the end of the cylinder head, with a narrow throat connecting the chamber to the inside of the head. On the compression stroke, the engine's piston forced highly compressed air into this chamber, and towards the end of the stroke fuel oil was injected into the throat, whereafter it came into contact with the chamber's uncooled walls. It instantly vaporized and then ignited, and the subsequent expansion of the hot gases forced the piston back down the cylinder and so provided the working stroke.

The Stuart engine did not rely entirely on compression-ignition for its action, because the pre-chamber had to be heated by a blow lamp for a few minutes when starting, but once the engine had started it was self sustaining. Not only was Stuart the first engineer to dispense with the need for a flame or spark for the main running of the engine, but he also used a "solid" injection system to force the fuel into the

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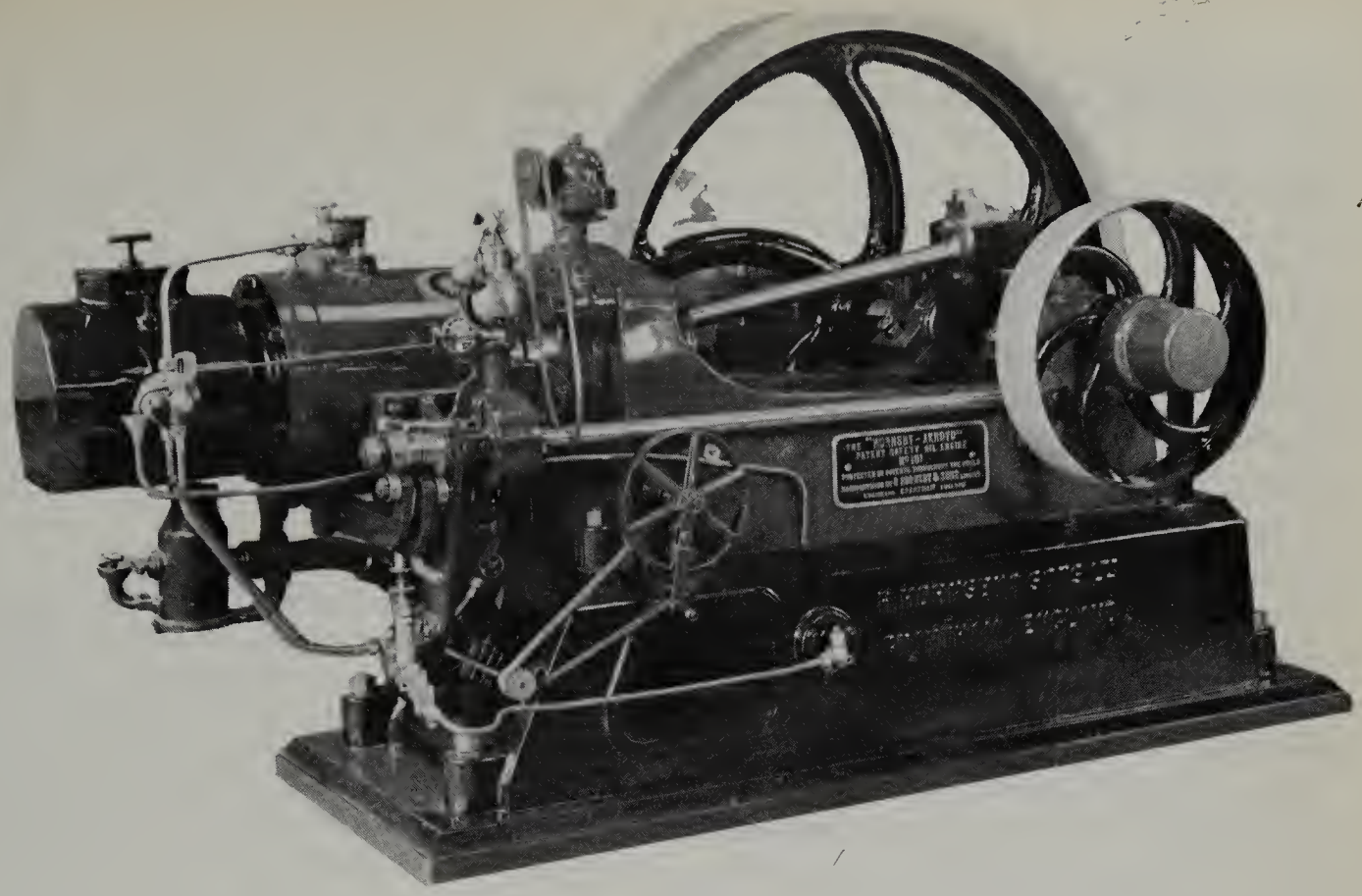
Advertisement for the "Hornsby–Akroyd Patent Safety Oil Engine." Production of this engine started in 1892.

chamber, and this was another important pioneering move, as we shall see in a later chapter. Stuart's injection system measured out the exact amount of fuel needed for combustion and ensured that it entered the chamber at the exact moment it was required, and in this way he overcame one of the main problems with previous engines, which were inclined to suffer premature ignition and so ran roughly and inefficiently.

Stuart used a fairly low compression ratio for his engine, the compression pressure being only 50 lb/in^2 (345 kN/m^2), so the thermal efficiency of the engine was nothing like as high as subsequent diesel engines were to achieve. But when running on paraffin or lamp oil the engine's running costs were low enough to be attractive, and in 1897 a water-jacketed vaporizer was added, which enabled the compression pressure to be raised and the fuel economy improved.



The Hornsby–Akroyd engine supplied to Fenny Stratford water pumping station in 1892, and later sold to a timber merchant to power a bank of saws. It had a maximum output of 9 horsepower at 200 revolutions per minute and ran on paraffin.

By this time, though, the engine had passed out of Stuart's direct control, because the manufacturing rights were acquired by Richard Hornsby & Sons Ltd., of Grantham, in 1891, who the following year started to build the "Hornsby-Akroyd Patent Safety Oil Engine." The engine was an instant success and sold in large quantities in all parts of the world. The initial types were of one horsepower and ten horsepower rating, but in due course Hornsby's were building engines of up to two hundred horsepower. Most of these were used for stationary purposes, especially electricity generation, but because they were self-sustaining they were also sold as portable engines for agricultural and mining purposes, and many were also built for use in merchant and naval ships as auxiliary engines.

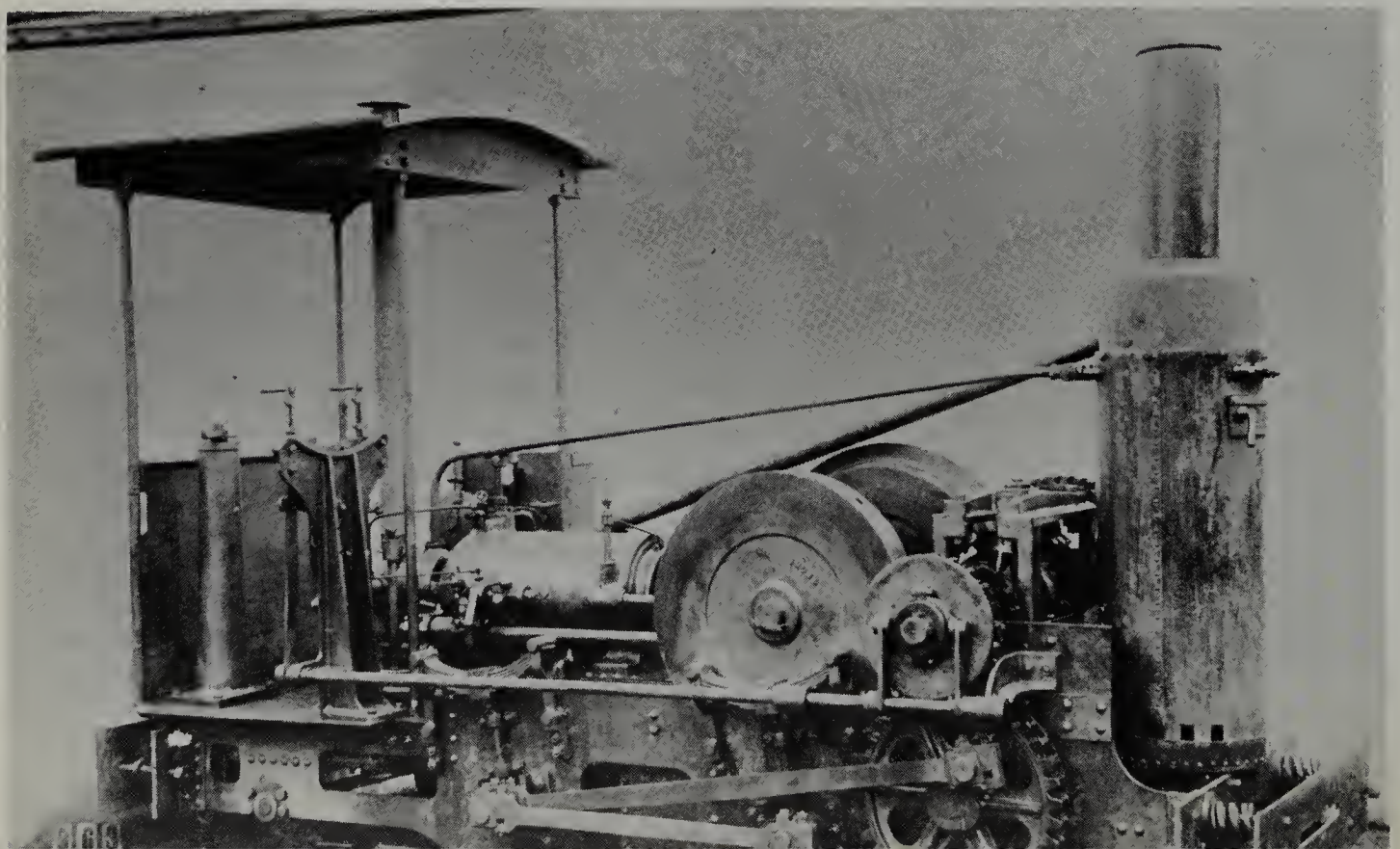
In 1895 the American patent rights of the Hornsby–Stuart engine were sold to the De La Vergne Machine Co., who had built five of these engines in 1893, and

after the patent agreement had been signed the engine went into series production for all manner of applications. The first Hornsby-Stuart engine built by De La Vergne has been preserved in the Smithsonian Institute, Washington, D.C., whilst the first engine sold, in 1892, by Hornsby's was repurchased by Ruston and Hornsby Ltd. (Hornsby's were acquired by Ruston, Proctor & Co. Ltd. in 1918), and this engine is now preserved by Ruston Paxman Diesels Ltd., at their Lincoln works.

We have travelled a long way through time in this book to reach the Akroyd Stuart engine, but it is important to see just how successive inventors and engineers sought to find a form of power that could be portable, economical, reliable, controllable and, above all, powerful. Steam still lives in the shape of the steam turbine, as invented by Sir Charles Parsons in 1884, but the steam turbine is used mainly only when very high horsepowers beyond the reach of present diesel engines are required.

The stage is now set for the main subject of this volume—Rudolf Christian Karl Diesel.

In 1896 the Hornsby–Akroyd engine was adapted for use in traction engines and light railway locomotives. The locomotive shown below was built for use on the narrow gauge railway of Woolwich Arsenal where, because of all the explosive materials in the area, an engine was needed which would not give off any sparks or fire while running. This locomotive had a 12.5 brakehorsepower engine.



3 *Rudolf Diesel*

In 1850, a twenty year old bookbinder left his home town of Augsburg, Bavaria, to seek his fortune in Paris, and within five years he had married a girl from Nürnberg who had also moved to Paris. The girl, Elise Strobel, was three years older than her groom, Theodor Diesel, and it had been necessary to go to London to get married because the Bavarian laws of that time did not allow their countrymen to marry in France. After the wedding, however, the young couple returned to Paris, where the following year a daughter, Louise, was born to them. On 18th March, 1858, the Diesels had a son, whom they called Rudolf Christian Karl, and in 1859 another daughter was born, this girl being named Emma.

In those days Paris was looked upon as being one of the most technically advanced cities in the world, so it

Rudolf Diesel's mother and father, Elise and Theodor Diesel.

is not surprising that young Rudolf started to take an interest in technical things at a very early age, including dismantling a valuable cuckoo clock and leaving it in pieces for his father to find. He was frequently punished by his parents during his early years for misbehaviour of this sort, but he was by no means a thoroughly bad child. Although he did not take to the French language too well, he spoke good German, and his mother, who had lived in London for some years before meeting Theodor Diesel, taught him English.

As for his schooling, he went to a local Protestant school, and there he showed exceptional talents, particularly in draughtsmanship, and even at the age of twelve he was awarded a medal by his headmaster for his academic prowess. By the time he was in his teens, Rudolf Diesel was taking a keen interest in all the wonderful engineering novelties that Paris had to offer. He used to wander round the streets for hours on end, sometimes delivering books for his father, but more often than not just roaming around looking for new things to see. These things included small steam engines and even the occasional gas engine, and one of the highlights of his young life was when his parents took him along to the Paris World's Fair in 1867. This was the exhibition at which Otto's atmospheric gas engine received so much acclaim.

Rudolf was fascinated by all the technical novelties displayed at the Fair, and he picked up a fair knowledge of developments in the world of technology by his frequent visits to the *Conservatoire des Arts et Métiers,* where there were numerous models of early steam engines, as well as one of the original Lenoir gas engines.

When Rudolf Diesel was still only twelve years old, the Franco-Prussian war erupted, so instead of being able to continue his schooling in Paris, he had to go to England with his parents and sisters, and the family left Paris on 4th September, 1870, arriving in Lon-

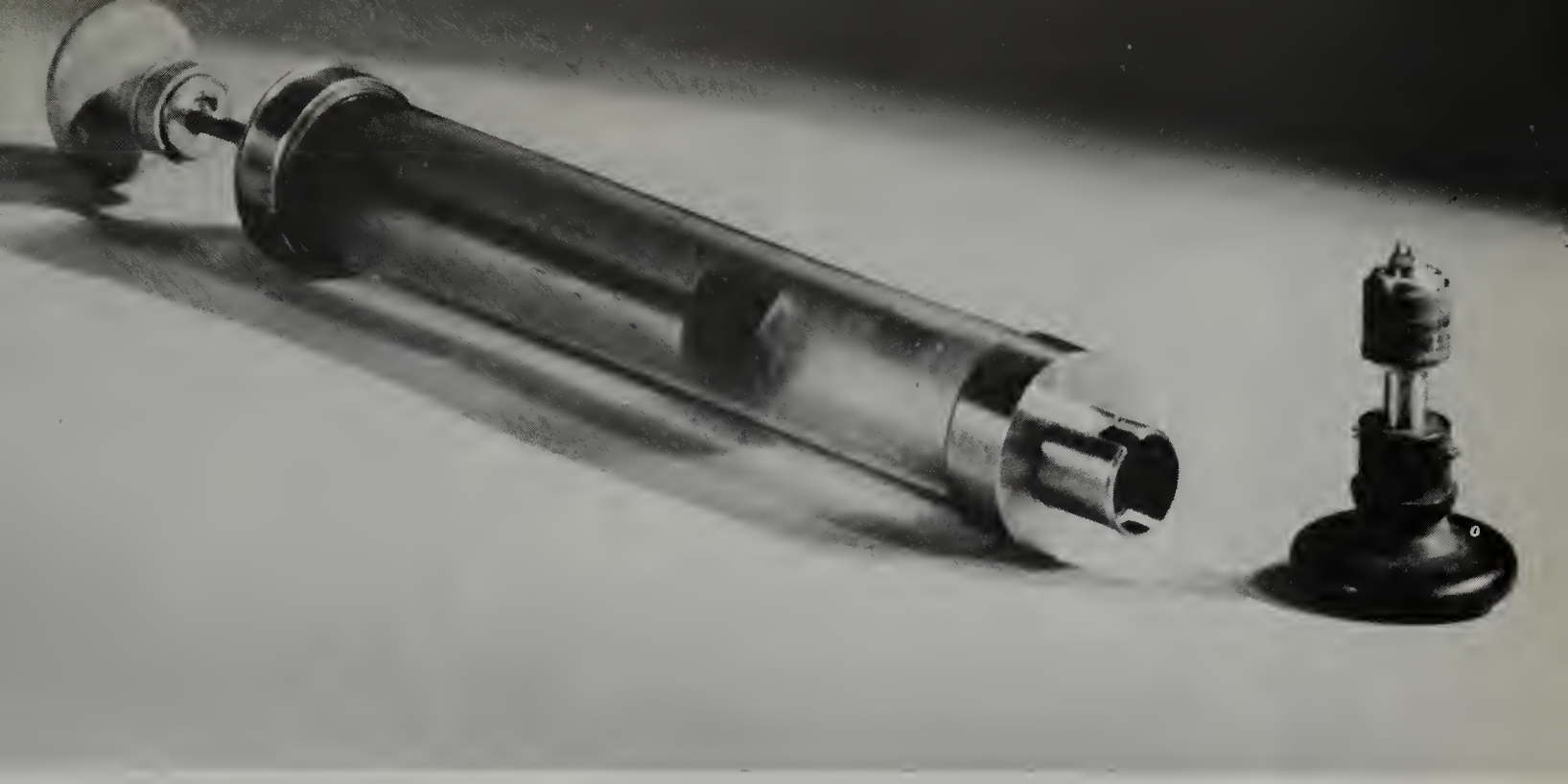
Rudolf as a young boy of twelve years old.

don two days later and finally finding cheap lodgings for themselves. Rudolf spent only eight weeks in London because his family decided that he should go to Germany to continue his studies. So in November the young lad undertook the long and tiring journey to Augsburg on his own.

In Augsburg, young Rudolf stayed at the house of Professor Christoph Barnickel, who was married to Theodor Diesel's cousin. As luck would have it, Professor Barnickel was a lecturer in mathematics, and he saw to it that Rudolf got a thorough grounding in this subject which was to stand him in good stead in later years. So the boy started his German school career at the Royal County Trade School in Augsburg, where he studied for three years before moving on. He had done well at the trade school, coming top of the final class at the age of fifteen, and by then his mind was firmly made up—he was going to be an engineer.

In October, 1873, he went to the industrial school in Augsburg to study mechanical engineering. He proved to be such an outstanding pupil that by the time he was eighteen he had won a scholarship to attend the Munich Technical School. One of the memories of the Augsburg school that never left him, however, was of a pneumatic tinder box which was used in the physics laboratory. This "fire machine" looked something like a bicycle pump made of glass, and when the plunger was pushed down the cylinder with force, a piece of tinder at the far end could be made to glow. This showed that when air is compressed, its temperature rises sharply, and it is not improbable that Rudolf Diesel had this tinder box principle in mind when he later turned his talents towards designing an engine.

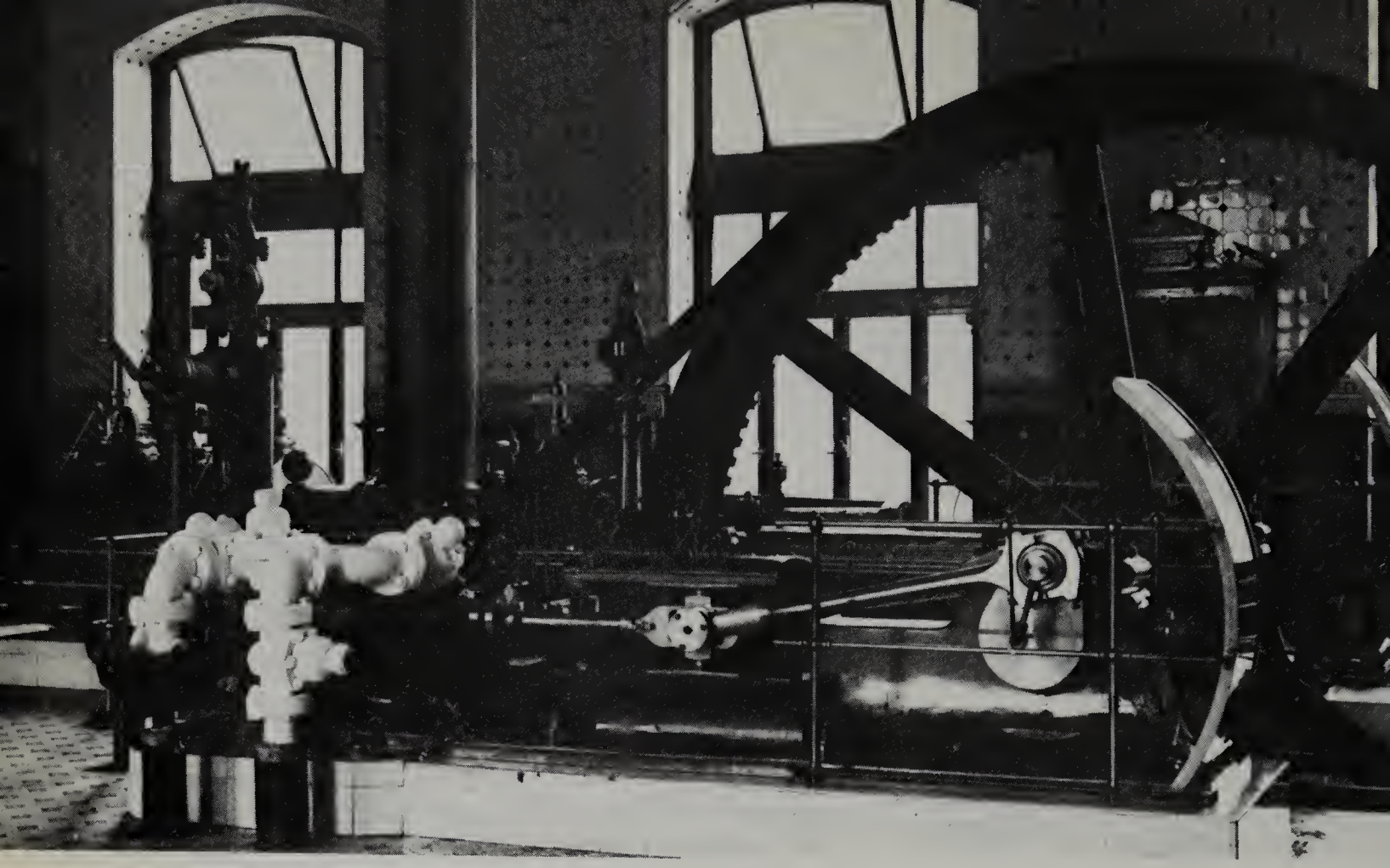
Anyhow, for the time being young Diesel was more interested in furthering his studies in engineering, though he still found time to improve his English, take piano lessons and attend orchestral concerts



The pneumatic tinder box, or "fire machine", which so impressed Rudolf at the Royal County Trade School in Augsburg.

(Wagner was his favourite). He was no weakling, however, and often used to take long walks. He was apparently a rather shy young man and did not join in the social life of his fellow students to any great degree. Most of his efforts went into his studies. One of his teachers was Professor Karl von Linde, who was an acknowledged authority on heat engines and refrigeration machines. One thing that Professor Linde said that stuck in Rudolf Diesel's mind was that even the most efficient of steam engines could not convert more than ten per cent of the heat energy in their fuel into work. He recorded in his notebook that this situation was worthy of further investigation.

When he was twenty-one, Rudolf Diesel became a naturalized German citizen, and soon after he was due to take his final examinations. Unfortunately, he fell ill with typhoid fever just before the examination session was due to take place, but because he had been such a brilliant student he was granted special permission to take the examinations the following year. He took them, and passed with the highest marks ever recorded in the history of the school.



An 1899 version of the icemaking machines made by the Sulzer Brothers in Winterthur, Switzerland, which is where Diesel got his first job.

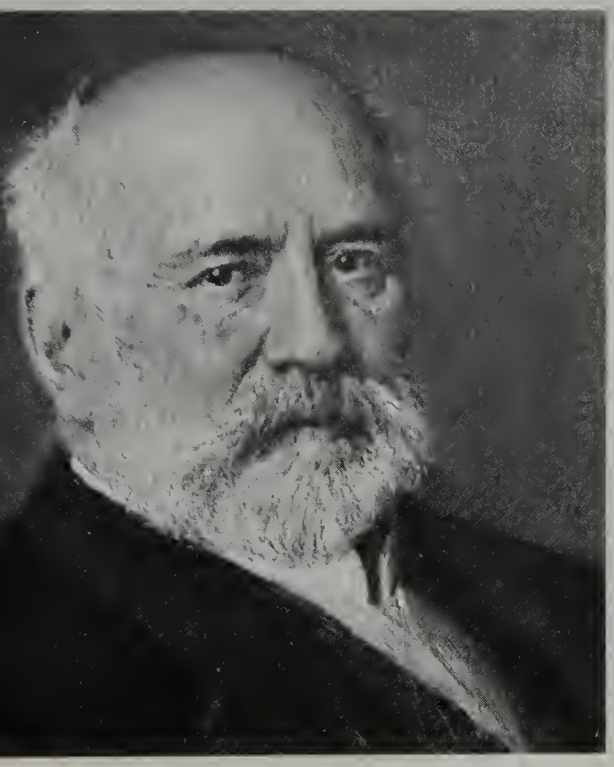
All the lecturers at the Munich school congratulated young Diesel on his performance, but one was determined that he should immediately take a practical step in the right direction. This was Professor Linde, who arranged for Diesel to go to the Sulzer factory in Winterthur, Switzerland, where Linde ice-making machines were being made.

He went to Sulzer's as a fully qualified engineer, but although he was going there to study refrigeration techniques, his mind was full of thoughts of designing an efficient heat engine. He had been much impressed while at Munich with what he had learnt about the Carnot cycle, the theory of which was that heat can only do work when it drops from a higher temperature to a lower one, and that heat must be introduced into a heat engine in a steady manner, at

constant temperature. Diesel was not to realize for some years to come that the Carnot cycle could never be achieved in a practical manner, since it ignored questions of friction and heat loss to the engine's surroundings from its cylinder. The Carnot theory referred to an *ideal* heat engine. Nevertheless, it—and Beau de Rochas' four stroke principle—were to inspire Rudolf Diesel in his later work.

The Sulzer works at Winterthur were engaged in building not only refrigeration machines but also boilers, pumps and steam engine valve gears, so they offered a young engineer like Diesel wide experience in engineering. He liked the practical work on the shop floor, and proved to be a good fitter, but because of his good brain and a knowledge of French it was only a matter of months before he was sent to Paris to the new Hirsch refrigeration factory. Diesel had been at the Hirsch plant for little more than a year before he was made factory manager, and because the refrigeration process used in the Linde machines involved the compression of ammonia gas, he started to work on the idea of designing his "ideal" heat engine with ammonia as the working medium. He also found time to handle the sales rights for Linde refrigeration machines in France and Belgium following the sale of the Hirsch plant, and on 24th September, 1881, he obtained his first patent—for a means of making crystal clear ice.

Heinrich von Buz (1833–1918), director of the *Maschinenfabrik Augsburg*, the great engine factory in Augsburg which was founded by his father, Carl Buz, in 1844. From 1893 to 1897 he gave Diesel the opportunity to test and develop his ideas.



Diesel's new ice making process did not appeal to Linde, but this turned out to be a stroke of luck for Rudolf Diesel. He wrote about it to Heinrich von Buz, a director of the *Maschinenfabrik* factory in Augsburg, and von Buz agreed to build machines to produce the crystal ice, at the same time inviting Diesel to spend some time at the Augsburg factory while the first machines were being made. Heinrich von Buz and the Augsburg factory were later to play an important part in the development of Diesel's engines.

Martha Flasche and Rudolf Diesel at about the time of their marriage in 1883.

Towards the end of 1882 he met a beautiful young German girl, Martha Flasche, and on 24th November, 1883, they were married in Munich, though they continued to live in Paris. A son, Rudolf, was born at the end of 1884, and a daughter, Hedi, a year later. But meanwhile Diesel was pursuing his idea of an "ammonia" engine in which superheated ammonia gas would take the place of steam in a steam engine, thereby enabling much higher compression pressures to be used than was possible with conventional steam engines. In this way he could make greater use of the heat energy of such an engine. He actually managed to make an engine along these lines

Twelve years later in 1895. Rudolf and Martha with their children Eugen, Hedi and Rudolf.

that worked, but ammonia is difficult stuff to handle, and by 1888 he was thinking of using air as a working medium instead of ammonia vapour.

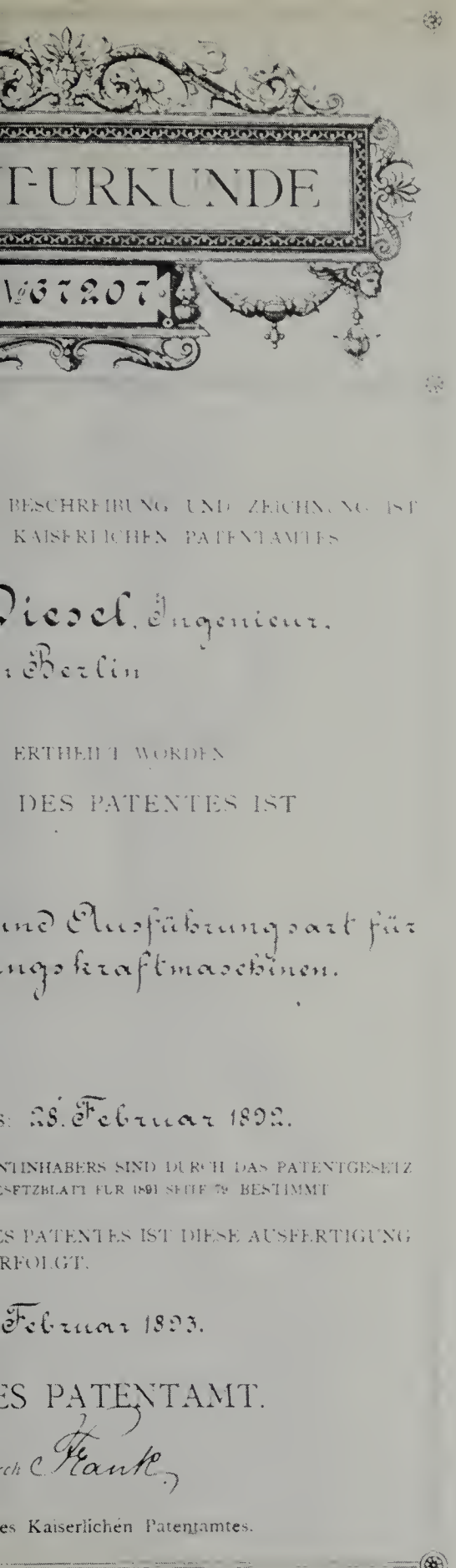
By this time the Benz and Daimler petrol engines were starting to make their mark on the engineering world, and Rudolf Diesel began to think along the lines of a high-compression heat engine using air and a liquid fuel. In 1890 he moved with his family to Berlin, where he was immediately accepted as somebody brilliant in the field of thermodynamics. In 1893 he published a short paper which he had written early in 1892. It was entitled, "Theory and Design of a Rational Thermal Engine to Replace the Steam Engine and the Combustion Engines Known Today."

The paper created great interest, but not a little controversy, largely because it proposed the idea of a Carnot-type combustion cycle in which the heat required for internal combustion in the engine was produced under constant temperature conditions, thereby avoiding the high temperature rise and the subsequent loss of heat energy that occurred with conventional engines.

The publication of Rudolf Diesel's paper came before he received his first German patent for a heat engine, (No. 67207), issued on 23rd February, 1893, and although Diesel's theories came in for a great deal of criticism, several eminent engineers were impressed, including Professor Linde, Eugen Langen (the same man who had worked with Otto), Professor Schröter and Dr. Zeuner. In November, 1893, Rudolf Diesel applied for a second patent (No. 82168), and this related to a much more practical engine.

The diesel engine was now within sight.

Rudolf Diesel's first patent (No. 67207) for a "combustion power engine," issued on 23rd February, 1893.



4 *Trials and Errors*

Rudolf Diesel's original aim was to design a compact internal combustion engine working on the principle of the Carnot cycle to obtain the maximum amount of work from a given quantity of fuel, but his initial ideas were not to work out in practice because he had made one or two miscalculations—as had other inventors of his day who were struggling to achieve the same ideal.

On the hundredth anniversary of Diesel's birth, Professor Dr.-Ing. Kurt Schnauffer read a paper in Augsburg which explains much of what Diesel had in mind when he wrote his theoretical paper and applied for his original patent. Professor Schnauffer quoted from Diesel's own private paper as follows:

"Both theory and practice had already led me to consider superheating of vapours (he was referring here to his "ammonia" engine), and my experience with the small engine I had built gave surprising proof of the advantage gained by superheating. I then developed a complete theory of a steam engine employing highly superheated ammonia vapour and by computation found that it would afford a substantial advantage over existing steam engines. Moreover, the engine thus conceived was distinguished by extraordinary compactness in comparison with existing ones due to the fact that advantageous utilization of the process not only required the employment of high temperature, but also of very high pressure.

"In order not to go astray, I also made the calculations for engines which would operate on highly superheated water vapour, and here again the necessity for high pressure became apparent because only a great pressure differential will permit the utilization of a steep temperature gradient during

expansion. It became apparent that the whole scientific material we have available on the behaviour of vapour was inadequate for further treatment of the problem. I extended the range of Regnault's steam tables up to very high temperatures, and found that under the circumstances the critical point was exceeded, with the result that the liquid phase and gas phase were no longer distinguishable.

"This gave me the idea to consider the vapour as a gas for the sole purpose of obtaining a better theoretical approach. In so doing, I discovered that there is practically no difference between vapour and gas: in other words, that I might also use gas or air while retaining the high pressure and temperature used in previous investigations. With high temperature, however, advantageous utilization of a normal combustion process was not feasible. This suggested combustion in the highly compressed air itself. The pursuance of this idea led. . . to the concept of the engine."

Professor Schnauffer points out that these theoretical considerations and computations are alone responsible for the creation of the diesel engine, and that the essence of Rudolf Diesel's bold concept was the use of an extremely rapid rise in temperature in an internal combustion engine by application of very high pressure. As Diesel was even thinking of pressures up to 3,555 lb/in² (24,435 kN/m²), it was no longer possible to compress the fuel together with the inducted air, due to the spontaneous ignition tendency of the fuel, so the air had to be compressed first and then the fuel had to be injected at the top end of the piston stroke into the compressed air, which by then would be at a temperature of anything up to 800°C and so would cause the fuel to ignite at once.

It is significant to note that Diesel's use of very high pressures was intended to obtain the highest possible thermal efficiency, and the ability to obtain self-ignition of the fuel came about as a subsidiary advantage.

The prototype diesel engine which was tested in July, 1893.

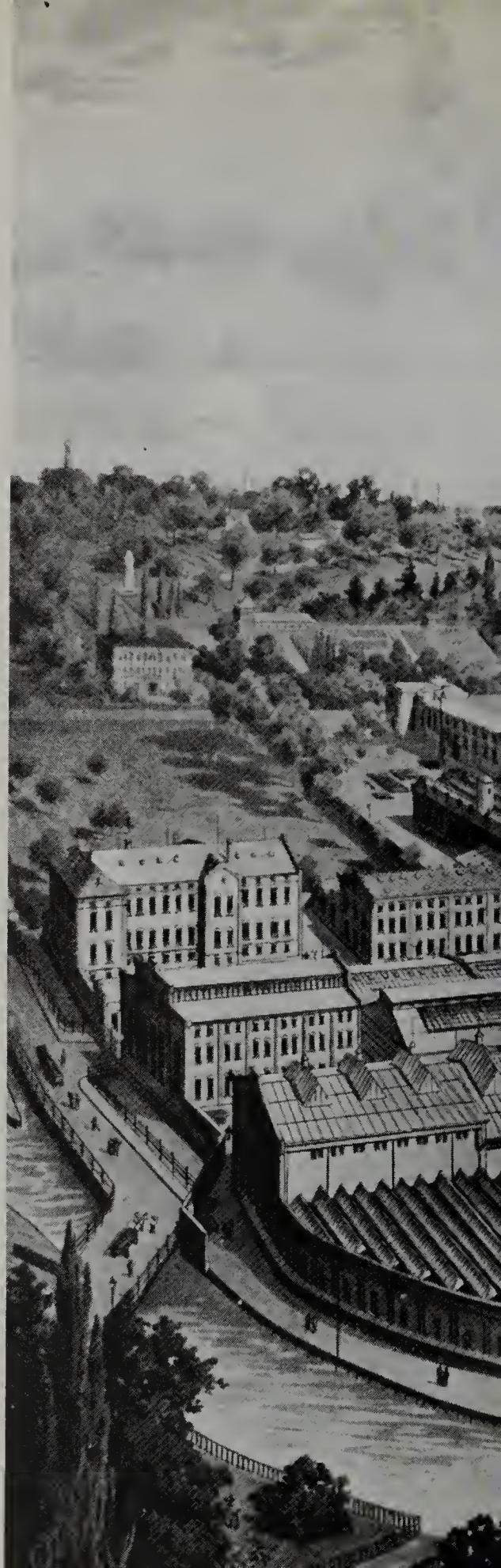
Rudolf Diesel's new engine theory had remarkable possibilities, because not only could it lead to an engine which could operate on liquid, gaseous or even pulverized fuels, but any type of combustion process could be used in it—constant volume, constant pressure or constant temperature. Unfortunately, Diesel remembered what he had learnt years earlier about the Carnot constant temperature cycle as taught him by Professor Linde when he was in Munich, and assumed that if he used this cycle he would achieve an engine thermal efficiency of 75 per cent and that the fuel needed would be only 10 per cent of that required by a steam engine of equivalent power.

But the Carnot cycle is not suited to an internal combustion engine because in isothermic combustion only a very small fraction of the air present in the combustion chamber can participate in the combustion process. But Diesel did not realize this at the time and he based his first patent application (27th February, 1892) on use of the Carnot cycle. Nevertheless, this patent did state two principles which were to be applied to all diesel engines: that only air should be inducted by the engine and that fuel should be injected after that air had been compressed, and that the degree of compression of the air should be high enough to raise the air's temperature to well above the ignition temperature of the fuel. This original patent application was rejected several times by the German patent office, so it was not until it had been revised that Diesel was finally granted patent No. 67207 on 23rd February, 1893. At least Diesel's patent office had the good sense to see that the references to the application of the Carnot cycle were less important than the references to non-mixing of the air and fuel before combustion and the use of a very high compression pressure, so the patent was rewritten to emphasize these two points and play down the Carnot cycle.

Earlier in 1892, however, Rudolf Diesel had already been in contact with Professor Linde, for whom he was still working in Berlin, in the hope of interesting Linde in building an engine to his new theories, but Linde expressed no wish to be associated with the exploitation of the invention, so on 7th March, 1892, he wrote to *Maschinenfabrik Augsburg* making a similar proposal, but with lower maximum pressures. But these pressures were still too high for an engine to stand and *Maschinenfabrik Augsburg* also told Diesel that they were not prepared to build his engine, and this led him to recalculate his theory and try to use a much lower pressure. Later in April he wrote to Heinrich von Buz, managing director of *Maschinenfabrik Augsburg*, again and in this letter he proposed a maximum pressure of only 626 lb/in² (4,316 kN/m²). He received no immediate reply to this letter. He then wrote to *Gasmotoren-Fabrik Deutz* (the company formed by Otto and Langen in 1872), and also to *Mannesmann-Werke*, of Berlin, but these letters brought no response either.

Diesel then resorted to a bit of subterfuge, and wrote to Professor Schröter at the Munich Technical University, sending a copy to Heinrich von Buz. In this letter, Diesel went into greater detail about his invention, and also made reference to the possibility of using coal dust as a fuel, with a pilot charge of petrol to achieve reliable ignition. This letter did the trick, and von Buz notified Diesel on 20th April, 1892, that his firm was prepared to start work on building an experimental engine.

So Rudolf Diesel signed an agreement with *Maschinenfabrik Augsburg* on 21st February, 1893. Unfortunately this did not involve any salary for Diesel while the experimental work was in process, and since he had estimated that it would probably take three years to perfect the engine he began to wonder what he would live on, so he decided to publish the paper already referred to in the hope of



The *Maschinenfabrik Augsburg* in 1900.

getting some income from this and of attracting greater attention for his invention.

The terms of the Augsburg agreement were that the company would build an experimental engine within six months and would pay Diesel a 2·5 per cent royalty. In turn, Diesel undertook to charge any other licensee not less than a 3·7 per cent royalty. On 25th February, 1893, Diesel signed a provisional agreement with Krupp, and the final contract was signed on 10th April, by which time the Augsburg and Essen companies had agreed to share the cost of building and testing an experimental engine, and to split any profits arising from subsequent production of the engine. The Krupp contract suited Diesel well, because it was agreed that he should be paid 30,000

Diesel's first co-workers. Pictured on the left is Lucian Vogel, an engineer at the *Maschinenfabrik Augsburg* who was responsible for many important components of the diesel engine. On the right is Immanuel Lauster, who joined the group in 1896 under the direct control of Diesel to help in building the second engine.

marks per annum while the engine was being developed, but it also included a clause which permitted Krupp to withdraw from the whole project at any time during the development period. With this income assured, Diesel was able to end his employment with the Linde concern and concentrate on his engine.

Diesel went one step further. He also contacted the Swiss Sulzer concern, and on 16th May, 1893, signed a provisional contract with them also, this allowing Sulzer's to build engines to Diesel's designs providing the tests to be carried out in Germany proved the value of the engine. Sulzer's did not want to involve themselves with the development of the engine, but at least they agreed to pay Diesel 20,000 marks a year.

By now one of Diesel's engineering student friends, Lucian Vogel, had joined him in his work, and on 17th July they went down to the Augsburg factory where a corner of a workshop had been set aside for the new "Diesel System" engine, to see what progress had been made with preparations for the building of the engine. It was nearly finished.

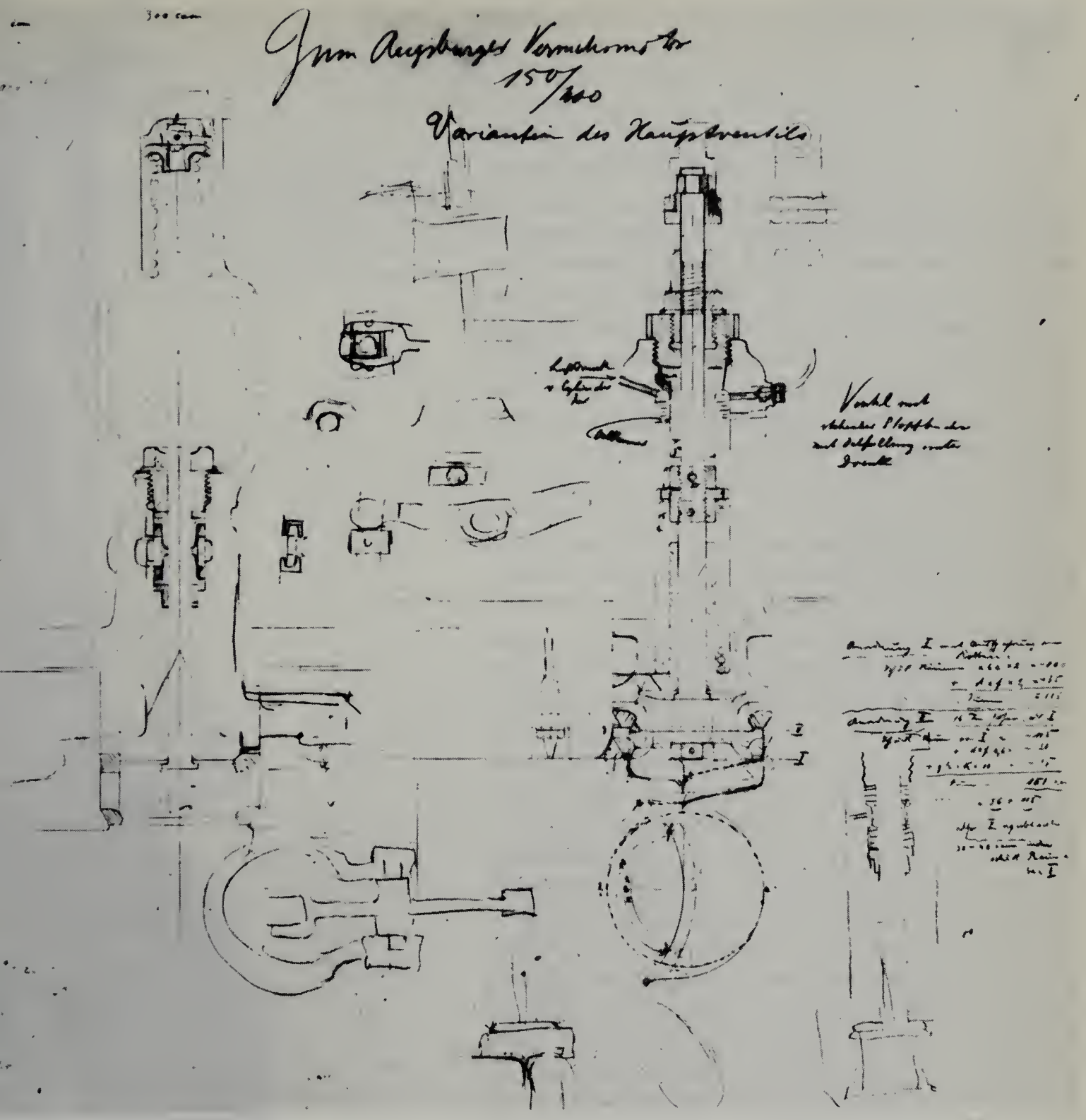
The engine itself was a massive structure, with a height of nearly 10 ft. (3.048 m.). The single vertical cylinder had a bore of 5·906 in. (150 mm.) and the piston stroke was 15·748 in. (400 mm.), the cylinder being supported by a huge A-frame. The cylinder was air-cooled, with a cast steel head and cast iron barrel, and cast steel was used for the piston, which originally had bronze rings, although later these were changed for cast iron. Although the engine was of the four stroke type, it had a combined inlet and exhaust valve, and there was a fuel-metering valve operated from the camshaft, this being fed by a fuel pump near the base of the cylinder. It will be noted that this first engine had "solid" fuel injection, thereby anticipating the types of fuel system used on current diesel engines. The engine was intended to produce about five horsepower. Tests were begun on 17th July, 1893.

It was originally intended to use a thick crude tar-like oil called *Pechelbrenner* as the fuel, but this could not be persuaded to flow through the fuel pipes, so lamp oil was employed. Prior to the tests with these thinner fuels, the engine was connected up by a belt to the factory's steam-driven power-transmission system so that it could be turned over without attempting to run it under its own power, and these first runs showed that the compression pressure was much lower than Diesel had planned, being in the region of only 260 lb/in² (1,800 kN/m²), but development work on the piston and valve enabled the maximum pressure to be increased to 494 lb/in² (3,400 kN/m²).

All this work had taken several days, and Rudolf Diesel was becoming impatient to see if his "dream" engine would work. On 10th August, watched by Lucian Vogel and his mechanic, Hans Linder, he turned the fuel tap on while the engine was being motored over by the factory belting. The liquid immediately ignited, but the resulting explosion was nearly the end of Rudolf Diesel and his helpers. The compression gauge which had been fitted into the cylinder head to measure the compression pressure burst, and pieces of metal and glass flew all over the workshop.

But the very force of this explosion indicated to Diesel that his theories were right, and during the next week or so more tests were carried out and it even made an independent start one day, although the engine turned only one revolution. But combustion was by no means perfect, and thick clouds of soot were emitted from the exhaust pipe. The tests established that a compression pressure of 425 lb/in² (2,930 kN/m²) would be sufficient, giving a compression temperature of 500°C, and Diesel made a note at the end of the tests. "It has been proved, even with this imperfect engine, that the process is capable of implementation."

Diesel's sketches for the 1893 prototype.


Jawa Ausgleichs Vergaser
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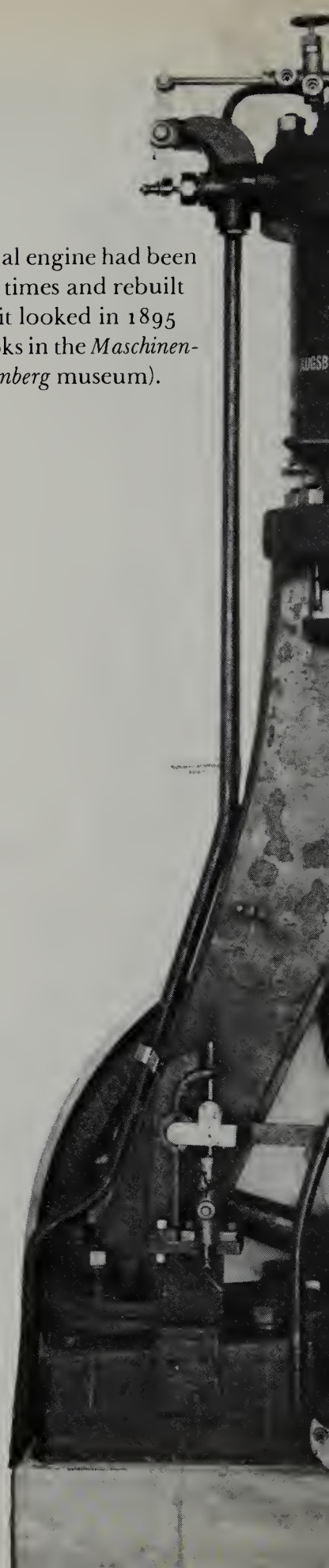
Variante des Hauptventils

5 *Success*

Within five months of these first tests, Diesel and his team were back at the Augsburg factory, and the original engine was rebuilt with separate inlet and exhaust valves, water cooling for the cylinder head and barrel and a compressed-air fuel-injection system to ensure that the liquid fuel was forced into the combustion space with sufficient pressure to overcome that of the air in the cylinder. This type of air-blast fuel injection was to become the standard system for many years to come—until Robert Bosch perfected the jerk-type pump in the 1920s, in fact. Diesel did not want to have to adopt air-blast injection. Not only did it complicate the engine, but it meant that an air compressor and air reservoir had to be provided, which in turn meant high production costs.

Work on the modified engine continued at a rapid pace, and one day in February, 1894, while the engine was being driven round by the factory belting, and while Diesel himself was occupied with some other task in the workshop, Hans Linder noticed that the drive side of the belt had slackened, which could mean only one thing—the engine was running on its own! It only ran for a minute, making little more than eighty revolutions in that time, but it *was* running.

At first, work on the second prototype went well, and the engine was found to be producing over thirteen horsepower. But it was clear that correct combustion was still not being obtained, and experiments were made with various types of fuel system. Diesel even tried to apply Bosch's magneto ignition to the engine, but this did nothing to help, and towards the end of the year Diesel was getting very depressed about the whole project. He even went so far as to build an engine that could run on town gas to make it



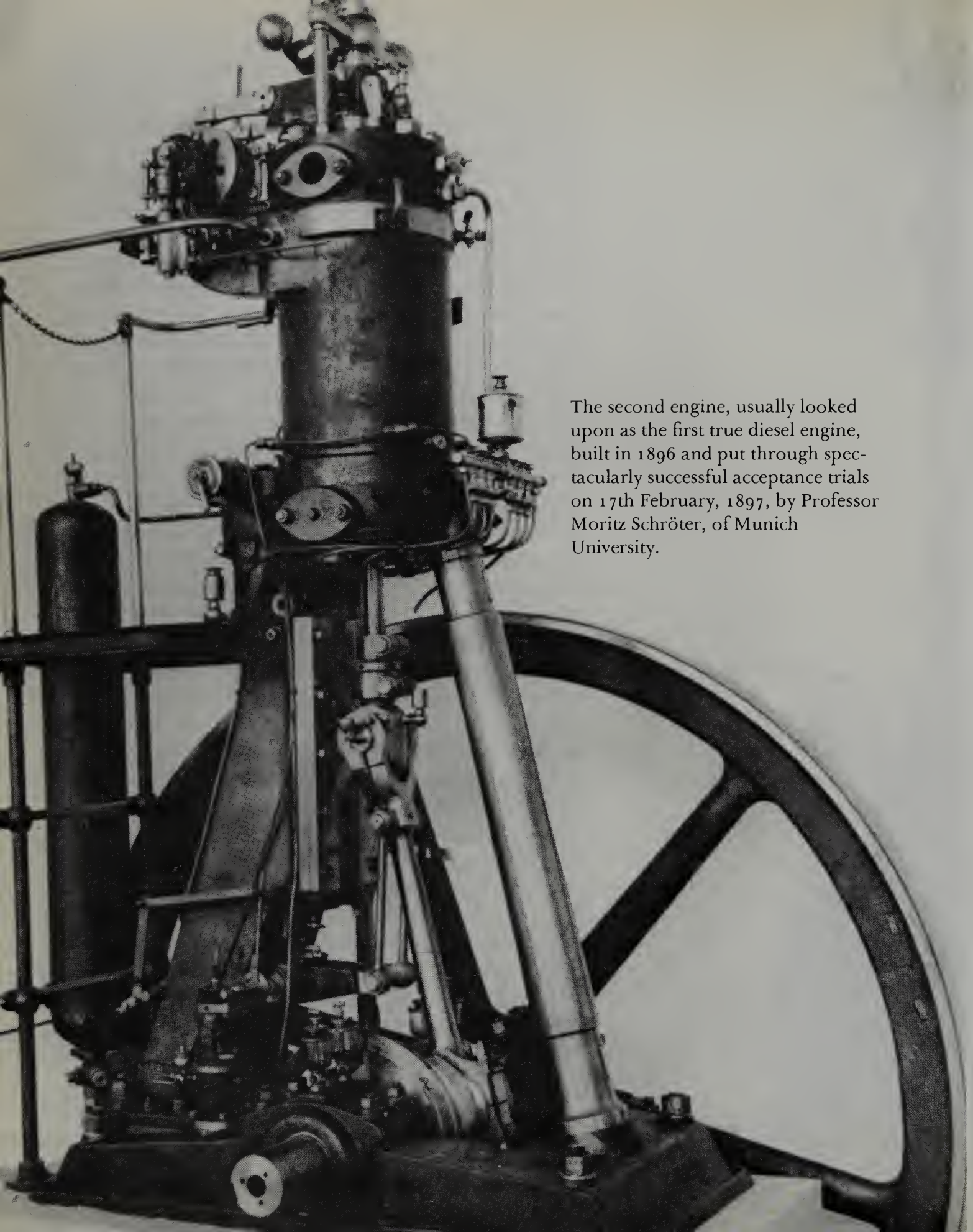
By 1895, the original engine had been redesigned several times and rebuilt twice. This is how it looked in 1895 (and how it still looks in the *Maschinenfabrik Augsburg Nürnberg* museum).

easier to study the combustion process and then apply any improvements to his liquid-fuelled engine. This gas engine venture was of great interest to Krupp's because they were building their own gas engines at the time, but the experiment did not work and Diesel abandoned the idea.

Early in 1895, Diesel changed his original prototype engine for the second time. Its cylinder bore was increased to 8.66 in. (220 mm.), the combustion chamber was moved from the top of the piston to the underside of the cylinder head, and the cylinder cooling arrangements were improved.

Tests with this new version started on 26th March, 1895, and these showed a big improvement in combustion efficiency. Kerosene was used for fuel at first, but later a light oil was employed. By May of the same year the engine was beginning to run reliably, with a smokeless exhaust, and it was producing twenty-three horsepower at a crankshaft speed of two hundred revolutions per minute. Tests of specific fuel consumption made in July indicated a consumption rate of only 0.85 lb per brake horsepower per hour (382 g/bhp/h), and this was less than half the fuel consumption of the other engines of that day. A brake thermal efficiency of over 16.5 per cent was being obtained in the engine. This meant that 16.5 per cent of the heat energy being supplied to the engine was being converted into useful work, and this heat energy was being derived from an inexpensive type of oil that was becoming readily obtainable. This thermal efficiency was at least twice as good as that of contemporary steam engines and half as good again as that of the best petrol engines, and was due almost entirely to Diesel's theory of using a high compression pressure to obtain maximum efficiency. More changes were made to the engine, and the efficiency was increased to over 20 per cent.

By the beginning of 1896 the engine had proved itself sufficiently reliable to encourage the directors of



The second engine, usually looked upon as the first true diesel engine, built in 1896 and put through spectacularly successful acceptance trials on 17th February, 1897, by Professor Moritz Schröter, of Munich University.

Maschinenfabrik Augsburg and of Krupp's to order that development testing should be reduced and that a pre-production engine should be built. This was more encouraging to Rudolf Diesel than it appears, because towards the end of 1895 Krupp had decided to withdraw from the whole project, and was only persuaded not to as a result of Heinrich von Buz's confidence in the engine.

So the original engine, which had been twice rebuilt in three years, was finally dismantled and stored away, and this historic piece of machinery can now be seen in the Augsburg museum of *Maschinenfabrik Augsburg Nürnberg* (M.A.N.), this being the company that was formed in 1898 when the Augsburg concern merged with *Maschinenbau-Actien-Gesellschaft Nürnberg*.

In January, 1896, Diesel set to work to design a new engine, helped now by a young engineer called Immanuel Lauster. The drawings for the new engine were completed on 30th April, 1896, one set going to the Augsburg workshops and another being sent to the Krupp works. The new engine had the same piston stroke as the original version, but its cylinder bore was increased to 9.843 in. (250 mm.), cast iron was used for the cylinder barrel, the water jacket and the cylinder head, a water cooled piston was adopted, and a one-piece combustion chamber was located between the top of the piston and the underside of the cylinder head.

Tests with the new engine started at the Augsburg factory in October, 1896, and after a few detail changes to the piston lubrication, the valve openings and the fuel pump, full scale performance tests were commenced towards the end of January, 1897. The new design was justified. The engine's thermal efficiency at full load was 26.2 per cent, the fuel consumption was 0.53 lb brake horsepower per hour (240 g/bhp/h), and the power developed was about 20 brake horsepower at 172 revolutions per minute.

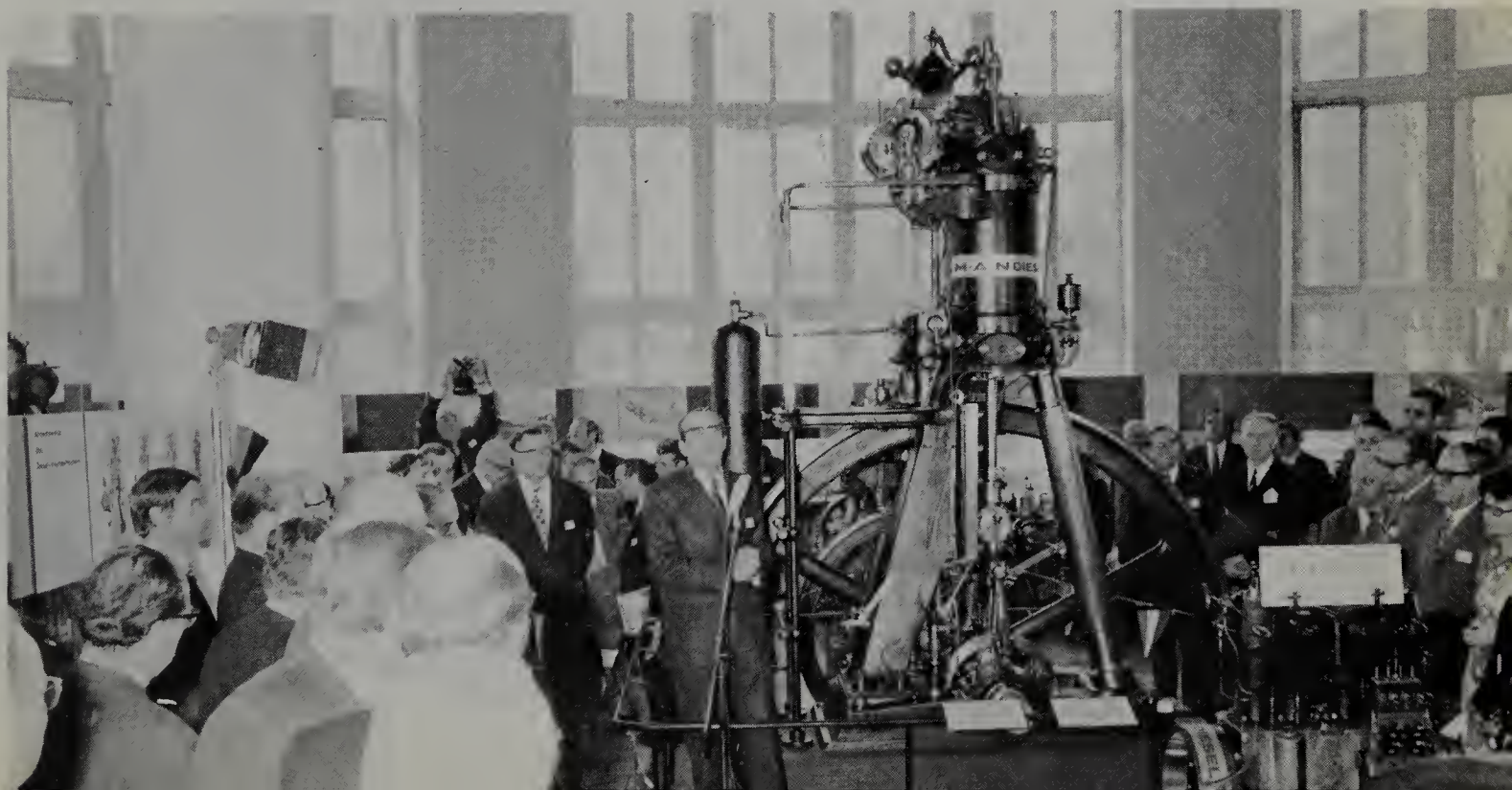
Left Rudolf Diesel, Heinrich von Buz and Professor Moritz Schröter at the 38th General Meeting of the Society of German Engineers at Kassel on 16th June, 1897.

These results were obtained with the engine running on kerosene, and the engine's efficiency was up to four times that of contemporary steam engines and twice that of any other type of internal combustion engine. The figures were unbelievable at that time and to ensure that other engineers would credit them, Diesel had an official acceptance test carried out for him by Professor Schröter, of Munich University.

Professor Schröter conducted the acceptance trials on 17th February, 1897, and so successfully did the engine pass its test that the Professor wrote a glowing report about it, indicating that it was the most economical heat engine in the world, saying that not only was it in a state of development that would make it readily marketable all over the world, but also that it promised to be the engine of the future.

This date, 17th February, 1897, is usually looked upon as being the birth date of the diesel engine, but it must not be forgotten that Diesel's original prototype had been running reasonably successfully three years earlier. The 1897 engine now occupies a place of honour in the Deutsche Museum, Munich, where it stands as a memorial to one of Germany's greatest engineering inventors.

Below M.A.N.'s technical director in Munich, Professor Doctor R. Klanner speaking at a press conference at the *Deutsche Museum*, Munich in February 1972 to mark the 75th anniversary of the diesel engine. He is standing in front of the 1897 engine.



The first British-built diesel engine and only the third built in the world, built in 1897 in Glasgow by Mirrlees Watson and Yaryan Co. Ltd. This engine is now on display in the Science Museum, South Kensington, London.

6 *Worldwide Acceptance*

With the successful trials of his engine completed, Rudolf Diesel became world famous almost overnight, and he was also starting to become a rich man. So much so, that he moved his family into a luxurious apartment in Munich, within relatively easy reach of the Augsburg factory.

His fame was not solely because he had invented a really economical heat engine, but also because that engine was being named after him. During the development days, Diesel had been referring to his engine as a Rational Heat Engine, but he realized this was too long and complicated, so he thought of various names, such as Delta or Beta. In 1895, however, his wife Martha suggested that the obvious thing to call the engine was just "Diesel," and this is the name that has stayed with this type of compression-ignition engine.

But Diesel was not to enjoy his fame and riches as much as he would have wished, because although his peace of mind had improved with the success of his engine, he could not shake off the terrible headaches that had plagued him since early childhood. Furthermore, although acclaim for his new engine was almost universal, and engineers came from all over the world to see the Augsburg engine running, he was now to be faced with numerous objections to his claim to have invented this type of engine, and this was to involve him in many long and costly legal struggles for most of the rest of his life.

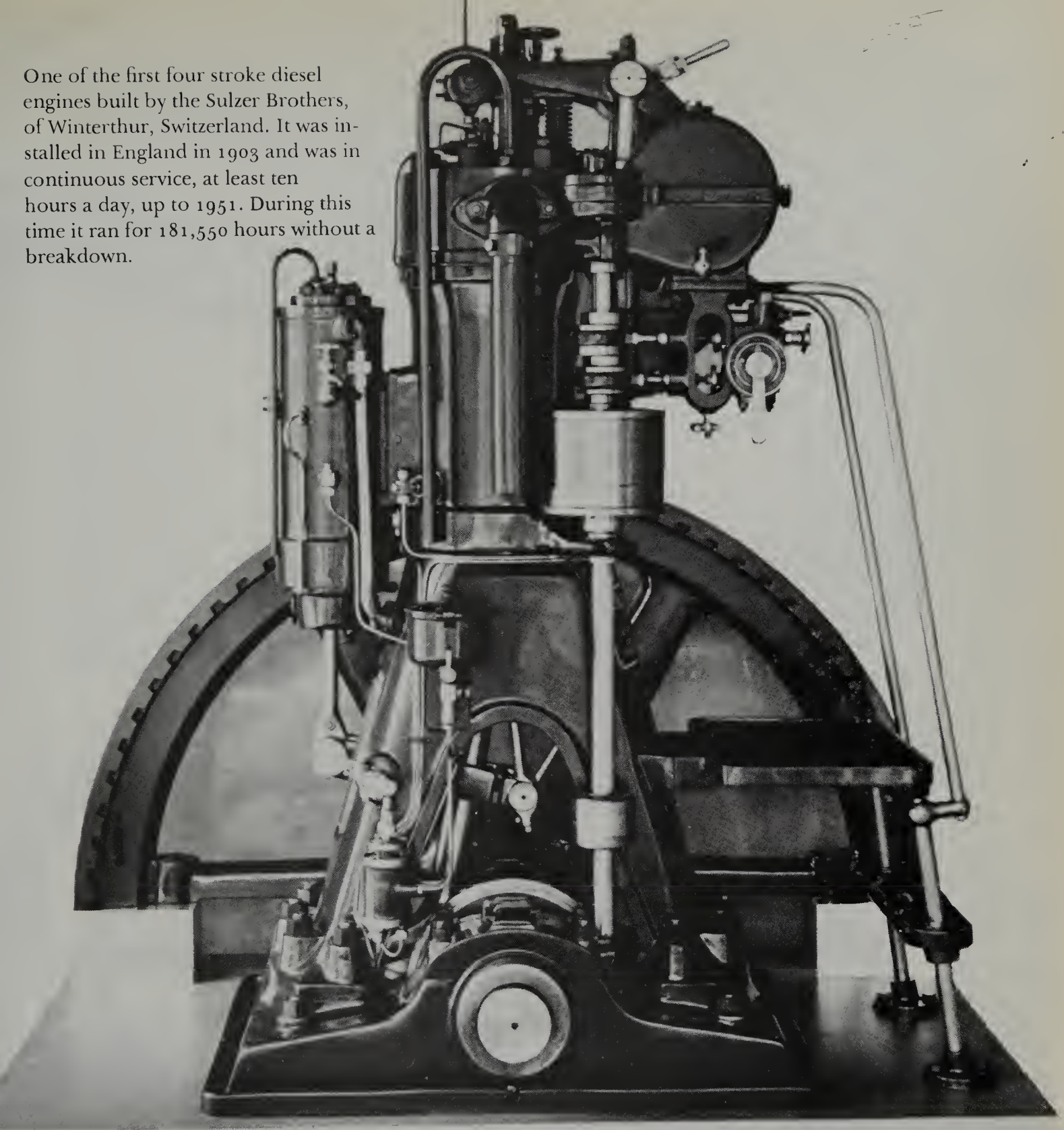
But for the time being life was sweet, though this did not mean that Diesel could rest on his laurels. There was still plenty of development work left to be done on the engine to give even greater efficiency. During the first half of 1897 the cylinder bore was in-

creased and the fuel-inlet system was again revised, and these changes raised the brake thermal efficiency to over 30 per cent. Many of Diesel's colleagues felt that the time was not yet right to offer the engine to prospective customers, and that more development should take place.

However, Rudolf Diesel was anxious to grant licences for his engine to be made by as many companies as possible, and one of the first of these licences went to the Scottish firm of Mirrlees, Watson & Yaryan Co. Ltd., of Glasgow, this contract being signed on 23rd March, 1897, making this the first non-German company to take on the building and marketing of diesel engines. Mirrlees, Watson & Yaryan became part of Mirrlees, Bickerton & Day in 1907, with a factory at Hazel Grove, Stockport, Lancashire, which is now run under the name of Mirrlees Blackstone Ltd., and the engine built in Glasgow in June 1897 is now on display at the Science Museum, South Kensington, London.

Diesel also concluded a licensing agreement with the Swiss Sulzer concern about the same time, whilst by June of that year a French factory was being built at Bar-le-Duc to build diesel engines under licence. Yet another licence agreement was that with *Maschinebau-Actien-Gesellschaft Nürnberg,* who, one year before they merged with the Augsburg concern, started the unsuccessful development of a five horsepower diesel engine for use in railway locomotives. This work was discontinued three years later because, as Diesel warned, it was too early yet to try to build a low-horsepower diesel engine for mobile applications.

On 16th June, 1897, Rudolf Diesel addressed the Congress of German Engineers in Kassel, and his paper convinced most of his opponents that the diesel engine was here to stay, even the Deutz engineers—who had questioned Diesel's rights to his various patents—being convinced that he was right after all. This resulted in *Gasmotoren-Fabrik Deutz*



One of the first four stroke diesel engines built by the Sulzer Brothers, of Winterthur, Switzerland. It was installed in England in 1903 and was in continuous service, at least ten hours a day, up to 1951. During this time it ran for 181,550 hours without a breakdown.

signing an agreement to build diesel engines in July, 1897.

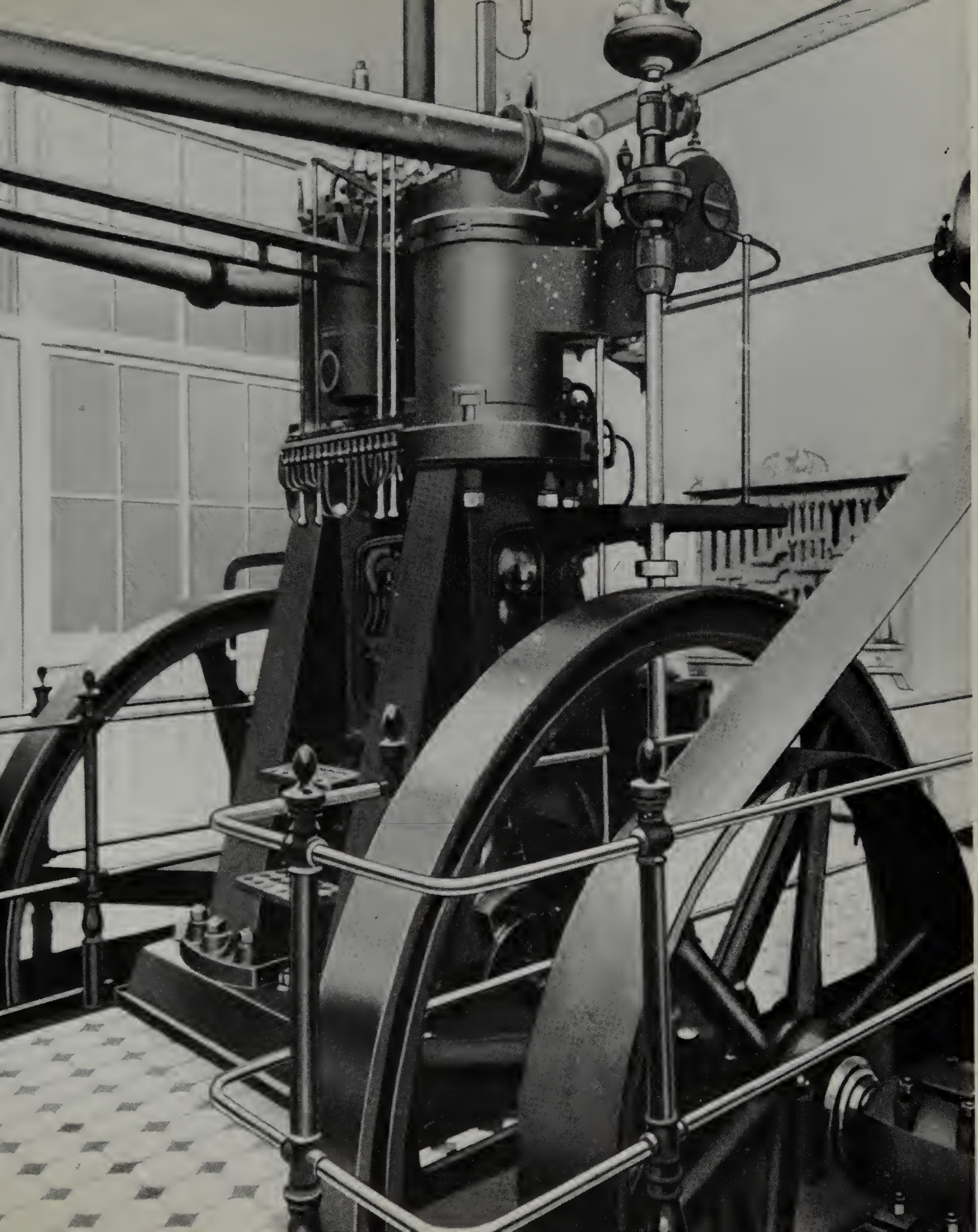
Another important licensing agreement signed in 1897 was with the American brewing magnate, Adolphus Busch, giving Busch exclusive manufacturing rights for the U.S.A. and Canada. With more than a little trepidation, Diesel asked Busch for one million Marks for this licence, and to his surprise Busch agreed to this without a qualm. Rudolf Diesel was now truly in the millionaire class, whilst Busch had his hands on the engine that in his opinion would replace the steam engine within years. Busch sold his first diesel engine in 1898, having formed the American Diesel Engine Company to build it. The company later became Busch-Sulzer, and in 1946 was absorbed by the Nordberg concern.

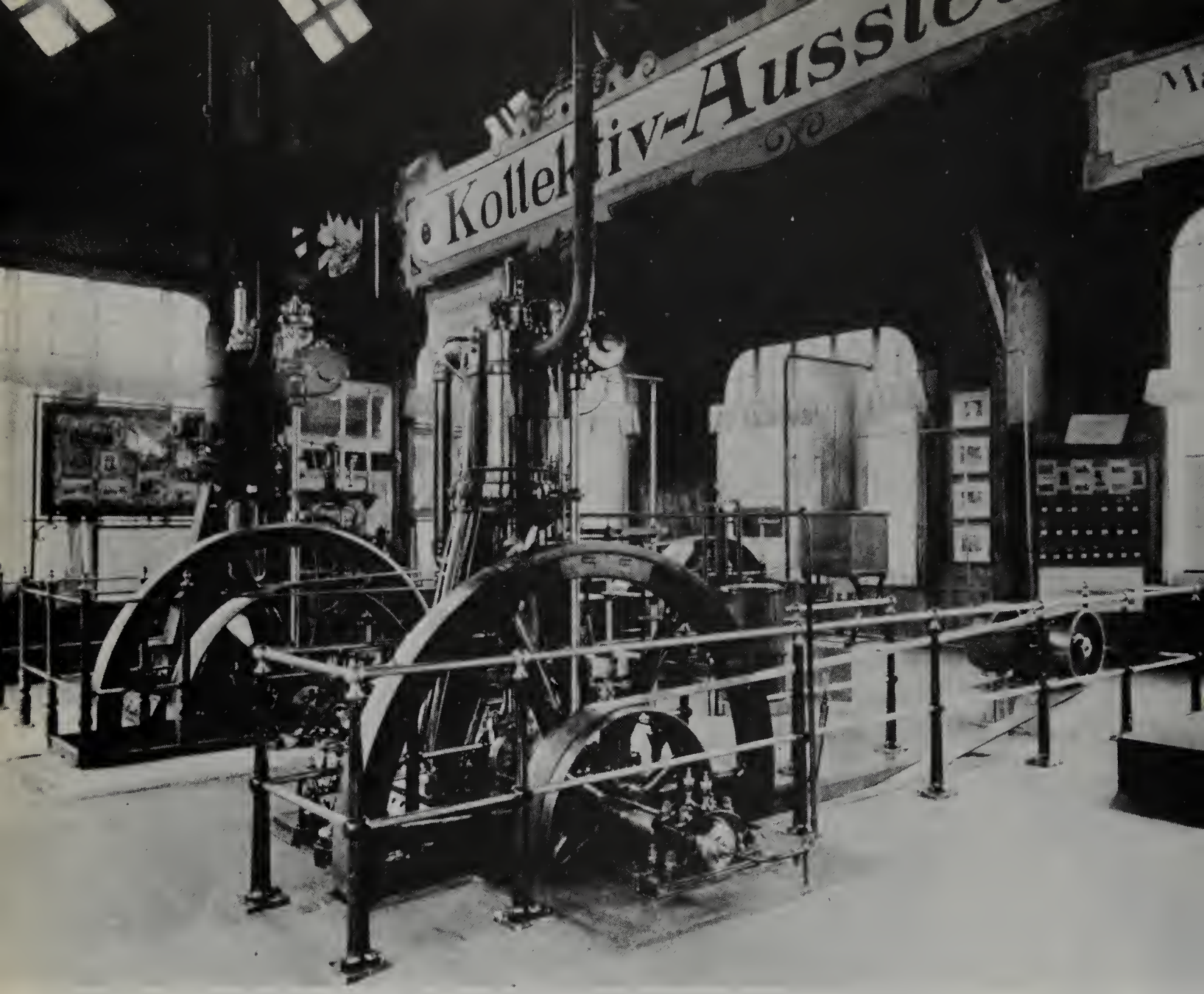
Building of the first production engine had started at the Augsburg factory by the end of 1897, and this twin cylinder sixty horsepower engine was placed in service at the *Zündholzfabrik* (match factory) in Kempten on 5th March, 1898, to become the first diesel engine in commercial operation. The engine was not without its initial troubles, but these were gradually put right, and the engine was reported to be running very satisfactorily for many years after its installation.

By this time, manufacturing licences had been granted to the Danish company of Burmeister & Wain, and to Vickers Sons and Maxim Ltd. in England. Carels had built one experimental engine in Belgium under the terms of their 1894 licensing agreement. In 1898, the Swedish oil magnate, Emanuel Nobel, signed a licence agreement to build diesel engines in St. Petersburg, Russia, and about the same time Marcus Wallenberg acquired the Swedish rights for the engine and formed *A.B. Diesels-Motorer*, which later became Atlas Diesels, now part of the NOHAB organization on Trollhättan, Sweden.

So even before the turn of the century, the diesel

The first diesel engine to go into commercial operation. This sixty horsepower, twin cylinder engine was installed in the Match Factory in Kempten in January 1898.





The Munich Engineering Exhibition, 1898, where four diesel engines were on display.

engine was becoming available in many different countries, and by 1900 there were twenty-five licencees, despite the fact that the engines were still by no means perfect and required very careful manufacturing techniques to make them work at all. But the advantages far outweighed the disadvantages: low fuel consumption, compactness, elimination of boilers, instantaneous starting from cold, elimination of fire risk, and ability to use cheap liquid fuel.

One bright spot of the year 1898 was the Munich

The Munich Engineering Exhibition. Rudolf Diesel and his fellow workers outside the exhibition hall.

Engineering Exhibition held in the summer, at which four diesel engines were on display from the Augsburg, Nürnburg, Essen and Deutz factories. These were actually working exhibits, and it was the first time that even one—let alone four diesel engines—had been put on public display. Diesel was justifiably proud.

Another event in 1898 that helped to put Diesel a little more at ease was the formation in September of a company to handle the foreign building rights for his

engine design, the new company also being responsible for future developments of the engine. This brought Diesel's finances into a happier state because he was paid over one million marks for his patent rights.

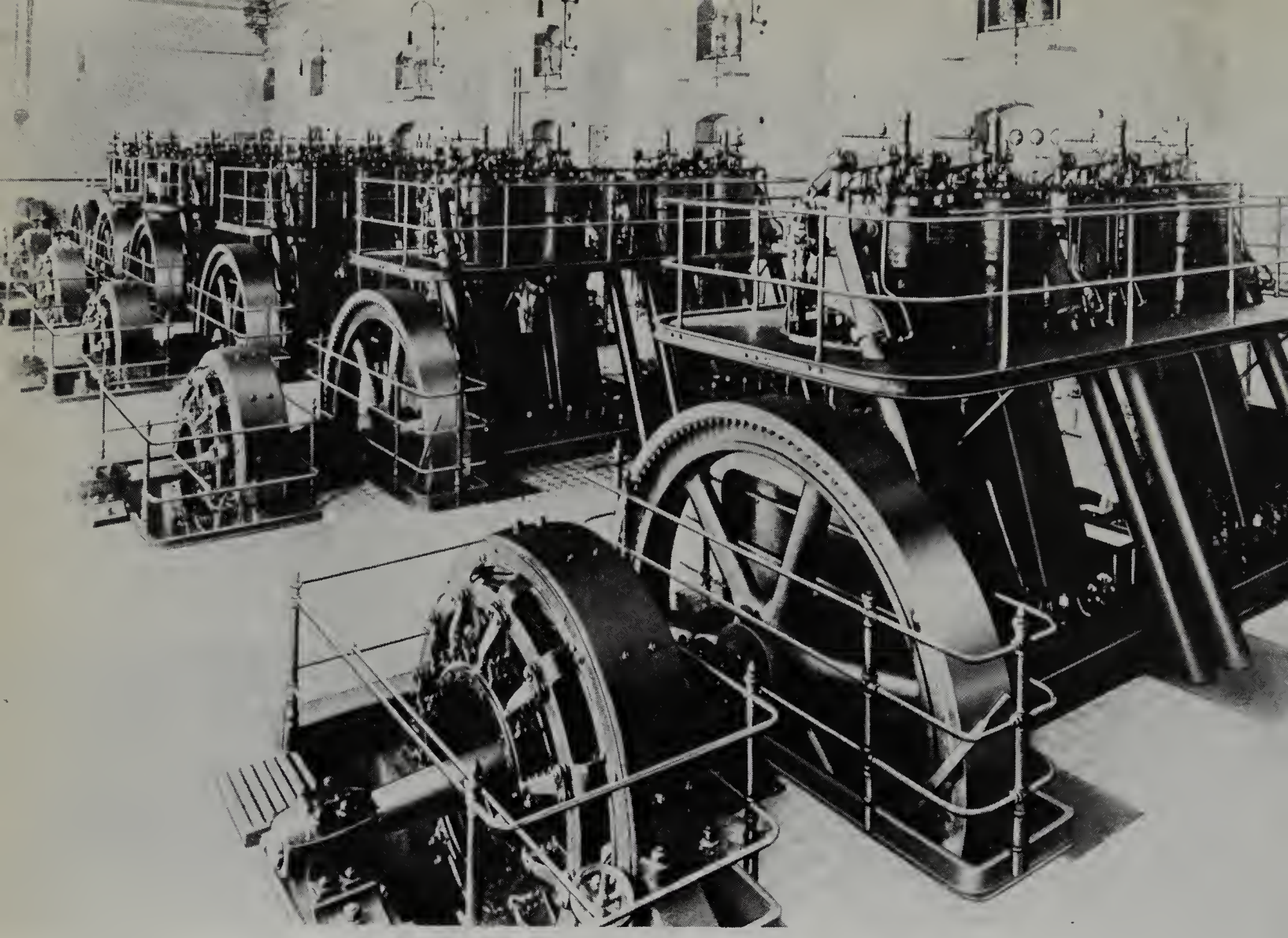
But his mental condition did not improve for very long, and in October he had to enter a nursing home for a rest cure, and then early in 1899 he took four months holiday in the Austrian Tyrol which seemed to improve his condition temporarily. On his return from holiday, he made some financially disastrous property deals, and wasted a tremendous amount of money on having a huge villa—complete with laboratory—built in Munich. He even wrote a book on social problems with the title *Solidarismus,* but this was a failure too.

So although his engine was becoming accepted and respected, Rudolf Diesel began to think of himself as a broken man, and his family life was by no means as happy as it should have been, his wife having become more interested in her husband's money and property and less interested in his inventive genius. To add to his troubles, he was now suffering from gout.

7 *The Final Years*

Rudolf Diesel entered the twentieth century with much past glory but little to comfort him at the present, but engineers had every confidence in his invention, and successful engines were being built in many parts of Europe and in North America. His fame as an inventor also continued to grow, and he was required to make many public appearances. In 1904 he went to America for the first time, but here he was less well known, and it was not until he returned on a lecture tour in 1912—this time with his wife—that he received the publicity he felt was due to him.

Rudolf Diesel and Thomas Alva Edison (1847–1931), the famous American inventor. They met while Diesel was on tour in America in 1912 and by all accounts they did not get on at all well. They even disagreed about food and drink. "Don't eat so much," Edison called out as Diesel left, two days earlier than planned.



The four four hundred horsepower diesel engines ordered in 1904 to provide electrical power for the city of Kiev's tramway system, together with the two additional engines installed in 1906.

In the meantime, the diesel engine was starting to grow up, and one of the first internationally important orders for diesel engines came from Russia in 1904, where the city of Kiev wanted four oil-fuelled engines, each of four hundred horsepower, to generate electrical power for the city's tramway system. Two more engines were added to this installation, and for many years this power station was to remain the largest diesel-powered establishment of its type in the world.

These four-cylinder engines were built at M.A.N.'s Augsburg factory, and this plant had meanwhile been carrying out important development work on engines

of the diesel type, including the building of one of the first trunk-piston diesel engines, as opposed to the crosshead type of diesel engine which all manufacturers had been building up until then. The trunk piston form of construction is employed for all current high- and medium-speed diesel engines (and for all petrol engines), and has the advantage of permitting a much more compact layout and higher rotational speeds.

In 1907 and 1908. Diesel's main patents expired, so he was enabled to carry on with some practical work. In 1909 this included cooperation with Klose of Berlin, and Sulzer's of Wintherthur, Switzerland, in building a 1,000 horsepower diesel-engined locomotive. Although this locomotive did actually run, it was by no means a success, but it was used for a while on the Hessian-Prussian State Railways: its failure was partly because of the use of direct drive between the engine and the wheels.

As far as road vehicle application was concerned, Diesel built a small engine of about five horsepower, and this won the Grand Prix at the 1910 Brussel's World Fair, whilst at about the same time he fitted a four cylinder diesel into a light van. But the trouble with these engines was that they were still much larger, heavier and more expensive than contemporary types of petrol engine.

Diesel was at least showing the way to the wider application of diesel engines. He was achieving something, even if there were no monetary rewards. Other engineers were in the meantime placing great importance on the diesel engine for marine power, and as early as 1903 Diesel himself sailed on a French canal barge which was the first waterborne craft to be powered by a diesel engine.

By 1912, Diesel was becoming more depressed than ever. He was still being attacked verbally by engineers in different parts of the world, who were claiming that Diesel had introduced no new theories or techniques,

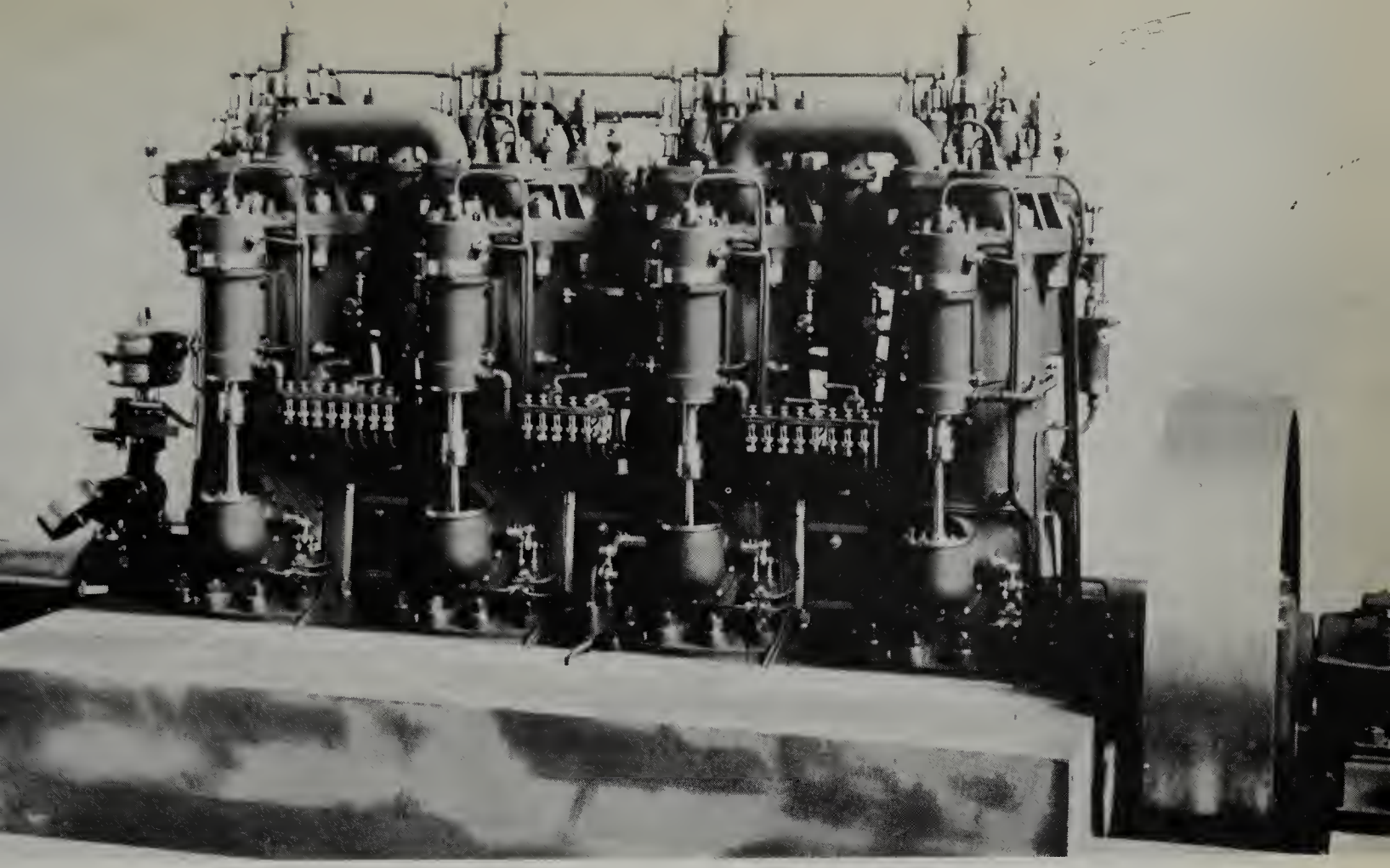
and that he had no right to be called the inventor of the "Diesel" engine. His financial speculations, particularly in property, were draining his former fortune and, although he weathered most of the storms of criticism and his fame actually grew, by the beginning of 1913 he had become a desperate man. It is recorded, in fact, that he lost over ten million marks through unwise speculations in under twenty years. His headaches and gout were as bad as ever, and in addition he was suffering from insomnia and had fears of heart trouble.

In August 1913, Diesel accepted an invitation to travel to England to be the guest of honour in October at the laying of the foundation stone for a new diesel engine factory in Ipswich which was being established by the Diesel Engine Company of England, this company having been founded in 1900 with Diesel as one of the directors. He also made a dinner appointment with his friend Sir Charles Parsons. He planned his visit to England for the end of September, and agreed to travel via Ghent, there to meet George Carels, whose company had been one of the very first to take up a manufacturing licence from Diesel.

On 29th September, 1913, Carels and Diesel boarded the steamship *Dresden* at Antwerp. When he stepped off the quay Diesel probably knew that he would never set foot on dry land again. Rudolf Diesel took dinner on board ship, and then retired to his cabin at about ten o'clock, leaving word for him to be called the following morning at a quarter past six

But when the steward came round to his cabin, it was empty, and the bunk had not been slept in. A search of the ship revealed Diesel's hat and neatly folded topcoat on the afterdeck, but of the inventor there was no sign.

Ten days later, a Dutch pilot boat found a corpse floating in the North Sea off the Dutch coast, and the crew took the body out of the water, removed certain identification papers and property, and then returned



The first four-cylinder ships engines built by M.A.N. in 1904 for the Imperial Dockyards at Kiel.

the body to the sea in the traditional manner of seafaring men.

Although it will never be known exactly what happened on board the Dresden on that night crossing, it is almost certain that Rudolf Diesel committed suicide.

Rudolf Diesel, just before he died that night at the age of fifty-five, was probably sufficiently artistic to conceal his troubled thoughts from his companion on the ship, but equally enough of a determined engineer to carry his intention through to its dreadful end.

The world had lost a genius, but it had gained economical power that was to revolutionize all forms of transport and industry, and was to carry the name of its inventor for all to remember.

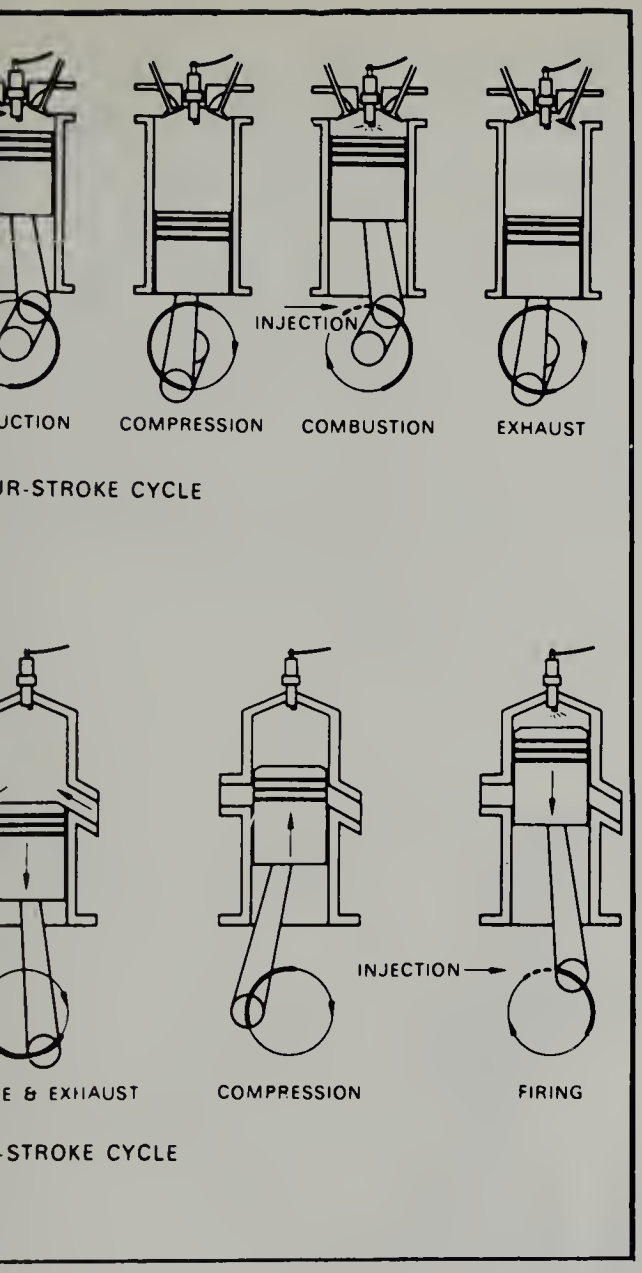
8 *Theory and Practice*

It is important to realize that no diesel engine ever worked successfully when Rudolf Diesel's original theories of over eighty years ago were followed. This was because Diesel originally wanted to adopt the Carnot cycle, with combustion at constant temperature. Fortunately, Diesel himself soon realized this, and he then decided that a constant pressure combustion cycle would have to be used. This means that the pressure in the cylinder stays constant during the time that the fuel is being injected and burnt, this phase being followed by expansion of the gases in the cylinder during the downward power stroke of the piston.

Although all the early diesel engines did have constant pressure combustion, the true principle has now virtually disappeared from the diesel world, with the exception of some low-speed engines, which got close to the constant pressure cycle, but which were large and heavy as a result. The modern medium- and high-speed diesel engine has only a very brief constant pressure phase, and its cycle is closer to that of the spark-ignition petrol engine, which has a constant volume working cycle. But these changes are just adaptations of Rudolf Diesel's first practical engines, and the basic principle of using high compression pressures to obtain maximum thermal efficiency and self-ignition of the injected fuel still applies and accounts for the overall economy of the diesel cycle for commercial applications.

So in simple terms the modern four stroke diesel engine works like this:

On the downward induction stroke of the piston, air enters the cylinder from the surrounding atmosphere, the inlet valve being open. Then as the

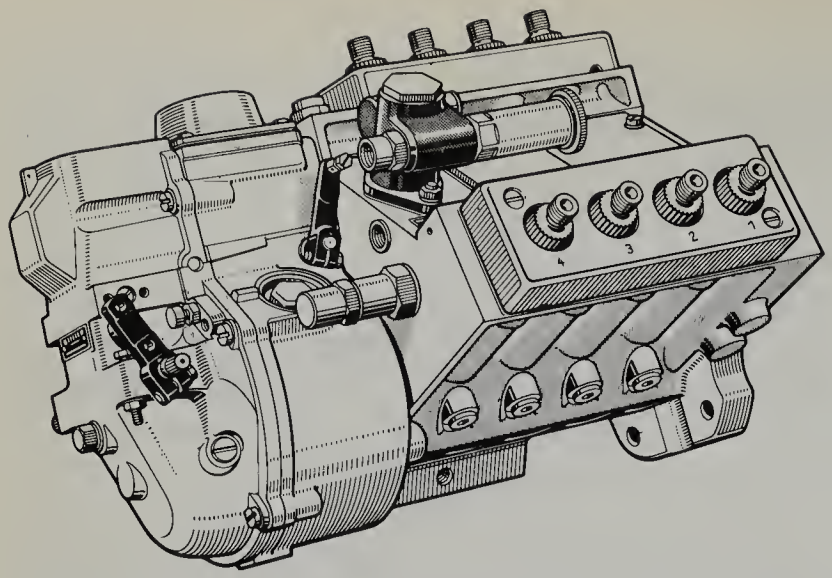


Four stroke and two stroke working cycles.

piston returns up the cylinder the air is compressed, with inlet and exhaust valves firmly closed. This air is compressed very highly, and its pressure in the cylinder before the fuel can be injected is at least as high as 600 lb/in² (4,150 kN/m²), so that its temperature is well above that at which the fuel will ignite, the fuel's self-igniting temperature being in the region of 400°C and the air's temperature being at least 100°C higher than this.

At a predetermined moment before the piston reaches the top end of its stroke, injection of the fuel into the small cylinder space above the piston takes place. This is one of the most critical phases in the diesel engine's cycle, and the fuel-injection equipment has to measure out a precise and minute quantity of fuel relative to the engine's needs at the time, to make sure that the fuel is atomized into tiny droplets so that it will burn readily, to control the total time of the injection period down to fractions of a second and, above all, inject the fuel at a high enough pressure to overcome the pressure of the air already in the cylinder—and this can involve injection pressures as high as 8,000 lb/in² (55,000 kN/m²). All this has to take place at a rate of up to two thousand times per minute per cylinder in the case of small, high-speed diesel engines, so the modern fuel-injection pump is a marvel of precision engineering. Any deviation from the engine designer's requirements in respect of fuel injection can result in drastic loss of engine power, high fuel consumption and the emission of exhaust smoke.

As explained earlier, Rudolf Diesel had to adopt a system of air-blast injection on his engines in order to force the fuel into the cylinder, and this method of fuel injection remained normal on all diesel engines until the mid-1920s. Air-blast injection was bulky, heavy and expensive, the pump required to compress the air absorbed power from the engine, and the working of the system made it impossible to run a

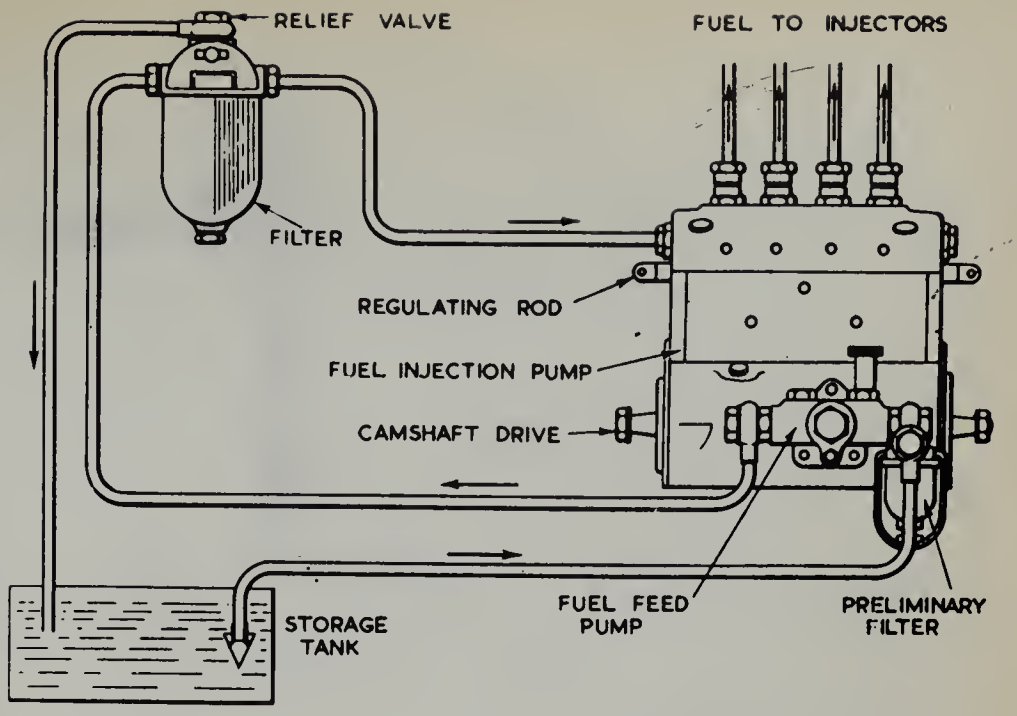


A modern Bosch fuel injection pump for use on an eight-cylinder diesel engine with cylinder banks in "vee" formation.

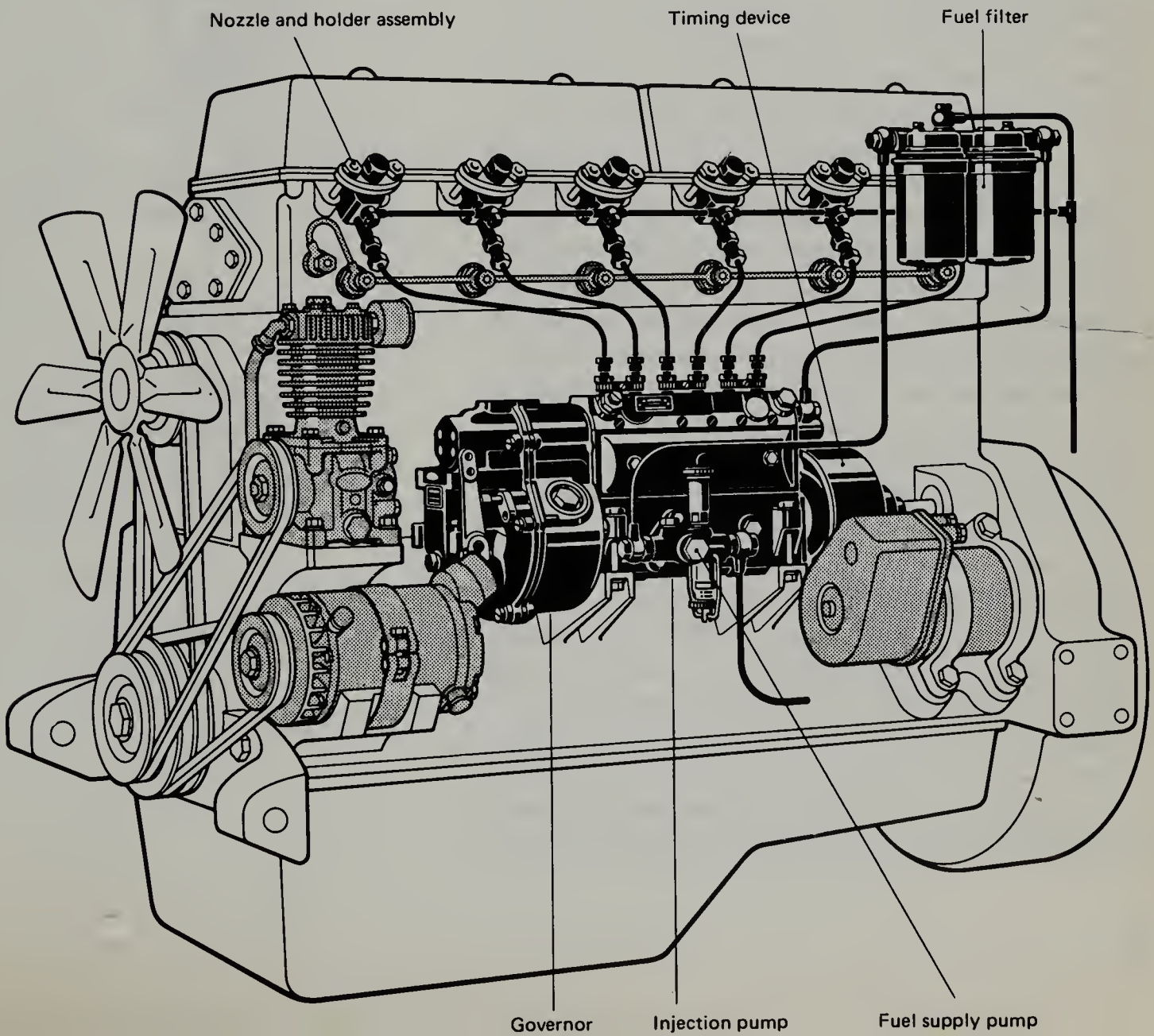
diesel engine at more than a few hundred revolutions per minute.

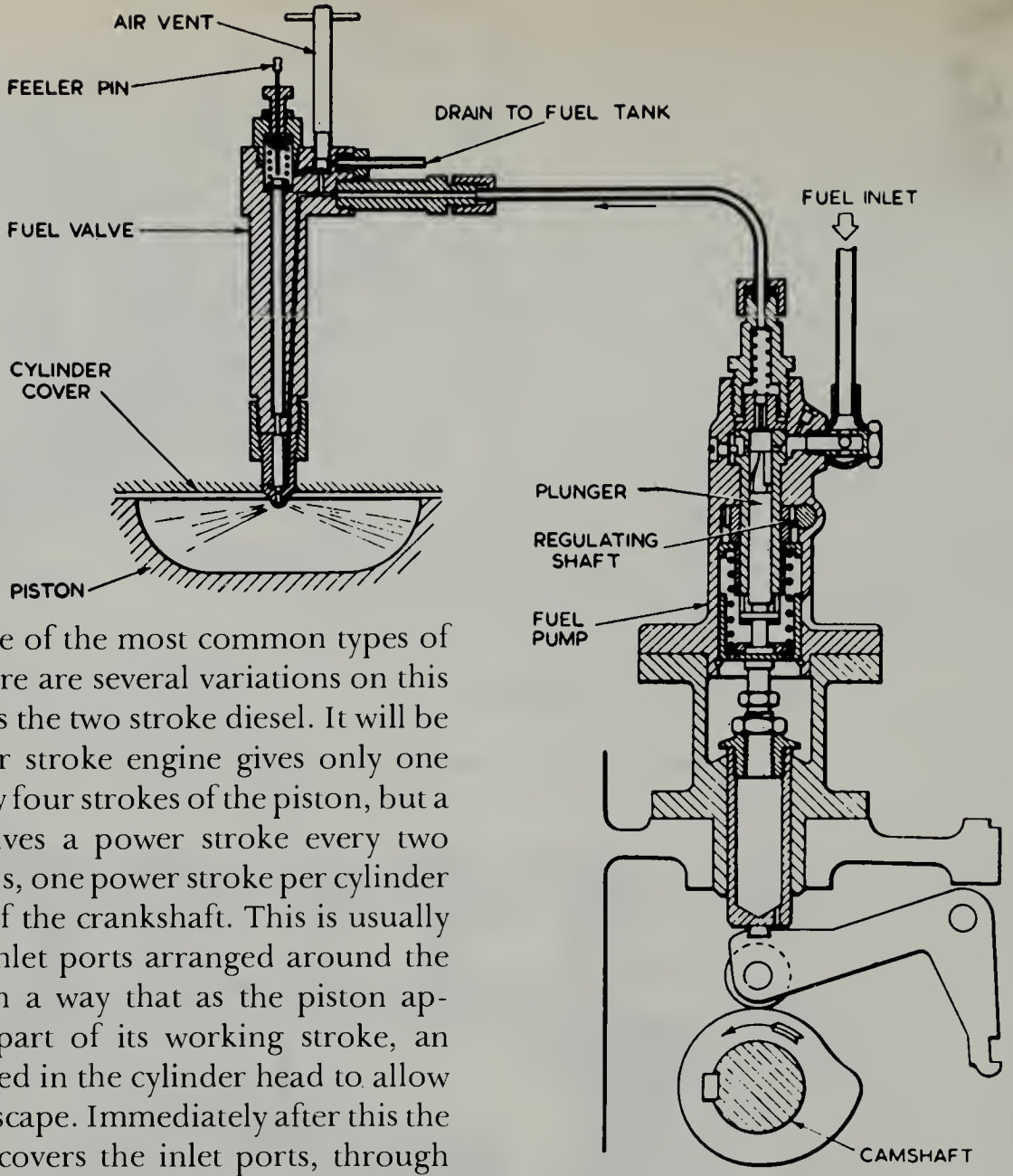
Diesel had tried to use a fuel-injection system without air blast, Akroyd Stuart used a type of "solid" airless injection on his engine, a Glasgow engineer, Alan Chorlton, patented a pump similar to the current "jerk" type, and in 1915 an airless fuel injection system was developed in Britain by Vickers for submarine engines, but it was not until the German Robert Bosch, perfected the jerk-type fuel injection pump of the type used today that the diesel engine really started to become practical as a small unit, and the first successful Bosch pumps were not placed on the market until 1926, and even then their principle of fuel control was based on a patent granted in 1892 to another German, Karl Pieper.

However, the fuel having been injected into the cylinder space commences to burn at a controlled rate, and the resulting expansion of the gases in the cylinder forces the piston back down the cylinder, so turning the crankshaft via the connecting rod. As the piston nears the bottom of its stroke, the exhaust valve opens to allow the spent gases to be released to the atmosphere. The piston then returns up the cylinder to drive the exhaust gases out completely, after which the inlet valve opens and the exhaust valve closes so that the next down stroke of the piston will draw fresh air into the cylinder for the next cycle.



Right A diagrammatic circuit for fuel injection equipment (for four cylinders) and *below* the actual arrangement in a modern six cylinder diesel engine (the fuel injection equipment is shown in black).





A typical arrangement of a fuel pump and injector.

This is the principle of the most common types of diesel engine, but there are several variations on this theme. One of these is the two stroke diesel. It will be obvious that the four stroke engine gives only one power stroke for every four strokes of the piston, but a two stroke engine gives a power stroke every two strokes, in other words, one power stroke per cylinder for each revolution of the crankshaft. This is usually achieved by having inlet ports arranged around the cylinder bore in such a way that as the piston approaches the lower part of its working stroke, an exhaust valve is opened in the cylinder head to allow the exhaust gases to escape. Immediately after this the top of the piston uncovers the inlet ports, through which air is forced into the cylinder under pressure by a supercharger or turbocharger. Some of this air is used to drive out the remaining exhaust gases, and the rest is compressed when the piston returns up the cylinder and closes off the inlet ports. The fuel is then injected into the cylinder as with a four stroke engine, whereupon the piston goes back down the cylinder under power until the exhaust valve opens to repeat the cycle.

There are advantages to either type of engine, although the two stroke cycle is used mainly for very large ships' propulsion engines, these being large-

bore, slow-speed engines capable of delivering up to four thousand horsepower per cylinder. In America, General Motors have been successfully building two stroke diesel engines for over thirty-five years, and these are used in road vehicles, railway locomotives, ships, generating sets, and so forth. Another well known high-speed two stroke diesel is the Foden, but, for the most part, the four stroke diesel engine has proved to be the more popular with users.

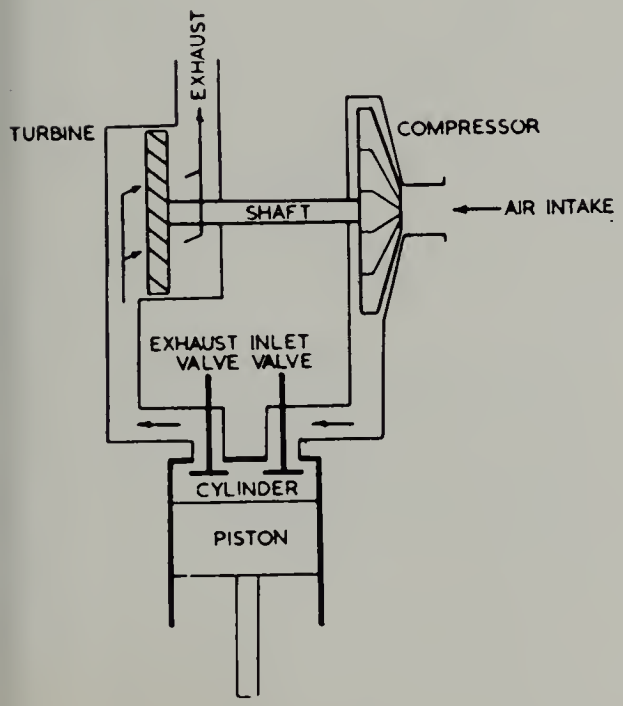
One reason for this has been the arrival of pressure charging. One way of increasing the power developed by a diesel engine is to increase the maximum speed at which it runs, but this leads to complications in view of the high stresses set up, so the alternative is—especially with the larger types of engine—to burn more fuel in the cylinder and so produce more thermal energy. But to burn more fuel, the engine must have more air in the cylinder, so this means that air has to be forced in by some form of external pump.

In 1911, Dr. A. J. Büchi started experiments at the Sulzer works in Switzerland with a "pump"—or air compressor—driven by the engine's own exhaust gases, and this was the original of what is now called the "turbocharger". The energy contained in the hot exhaust gases is used to drive a small turbine, and this turbine in turn rotates a small compressor which feeds air into the engine's cylinders at a pressure above that of the atmosphere. In this way, the engine receives more "breathing" air than it would when normally aspirated, and this extra air is derived from a power source that would otherwise have been wasted—the engine's own exhaust.

An alternative method is to use an engine-driven mechanical supercharger to provide the extra air, but because this type of device absorbs some of the engine power to drive it, the additional power gain is less than with a turbocharger.

A further development beyond the simple use of

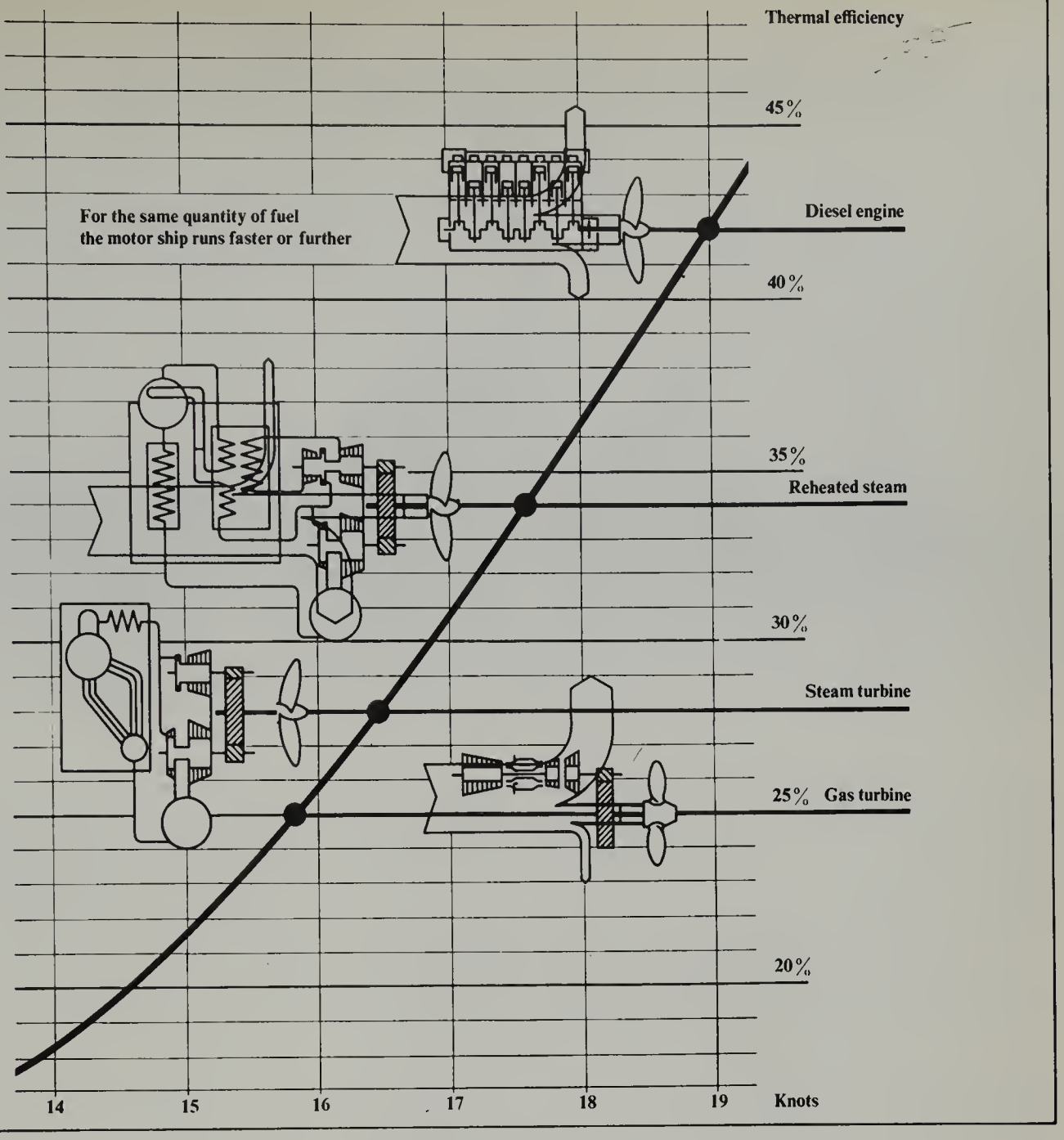
A diagrammatic arrangement of an engine and turbocharger. Dr. A. J. Büchi had started experiments to make use of the exhaust gases of internal combustion engines in 1911 and in the early 1920s the Büchi system of gas turbocharging went into commercial operation.



turbocharging is to cool the compressed air before it enters the cylinders. It is the mass of air that can be induced into the cylinder that decides how much fuel can be added, and therefore how much power can be developed by the engine. The turbocharger increases the volume of air that can be admitted, but because it has been compressed this air has become heated, and therefore its density is reduced. That is to say, its mass related to volume is lower than it would have been if the air had not been heated.

The answer to this is to cool the pressure-charged air before it can enter the cylinders, and this is known as charge cooling. By cooling the air in this way, its density is increased, so a greater mass of air can be taken into the cylinders. Either water or air can be used to cool the charge air, and the device used is called an intercooler or aftercooler. By use of charge cooling, a given engine can be made to deliver more than twice the horsepower that it would without turbocharging, and in this way very high specific outputs and thermal efficiencies can be obtained. So much so, that thermal efficiencies of modern large diesel engines are now well over forty per cent, which is much higher than any other type of engine and two and a half times that which Rudolf Diesel obtained from his first running engine.

It has sometimes been stated that Rudolf Diesel designed his first engines to run on powdered coal dust, but this is not true, even though after his engine type had been proved successful in 1897 he did receive some encouragement to try to adapt his engine to run on this form of fuel. Various types of liquid and gaseous fuel were used by Diesel during the early days of his engine, ranging from the unsuccessful use of the *Pechelbrenner* sticky crude oil in the very first engine built in 1893 to various mixtures of petroleum, lamp oils, gasoline, waste oils, tar oil, shale and gas oil. But as for coal dust, the coal-burning diesel engine never really got beyond the experimental stage.



This graph compares various types of engine used at sea. It shows the thermal efficiencies of a large slow-speed diesel engine, and for steam and gas engines for ship speeds of 14 to 20 knots.

Nowadays, diesel engines run on gas oil distilled from crude oil, but the larger engines of the medium- and slow-speed types can operate on much cruder—and cheaper—types of residual fuel. There are also the "multi-fuel" types of engine that can run on petrol, paraffin, gas oil or certain types of crude oil, whilst another variation is the "dual-fuel" engine which burns gas, with a small pilot charge of diesel fuel.

9 *The Diesel Engine Today*

As we saw in Chapter Two, after the successful development of the gas burning internal combustion engine, engineers such as Nikolaus Otto strove to achieve an engine that would be self-contained with regard to its fuel needs, and not tied to a gas pipe.

Rudolf Diesel achieved this, of course, and with far greater efficiency than his contemporaries who were working on petrol and gas engines. Yet the first practical applications of diesel engines were all stationary, land-based installations. These ranged from the very first diesel engine to be sold commercially, the twin cylinder sixty horsepower engine supplied to the Union match factory at Kempten in March, 1898, to the four engines with a total horsepower of 1,600 which were built by M.A.N. for Kiev's tramway power station in 1902. Even in 1912, over ninety per cent of diesel engines in use were engaged on stationary duties.

But it was not long before the ability of the diesel engine to develop high power with maximum fuel economy attracted the attention of marine engineers, and at the beginning of the twentieth century diesel engines were being fitted to vessels working on inland waterways in Belgium, France, Germany, Russia and Switzerland. In 1908, a Dutch licensee of diesel engines (now called *Stork-Werkspoor*) installed 160 horsepower diesel engines in two former steam ships, the *San Antonio* and the *Cornelius,* and these became the first diesel-engined ships to put to sea. Already by this time the first use of diesel engines in a submarine had been successfully applied in France, and Scottish-built Mirrlees engines had been ordered as auxiliary power units in the Royal Navy's H.M.S. *Dreadnought.* Another notable sea-going diesel engine was the 180

H.M.S. Dreadnought, launched in 1906, was one of the early users of diesel power at sea. Scottish-built Mirrlees engines were used on it as an auxiliary source of power.

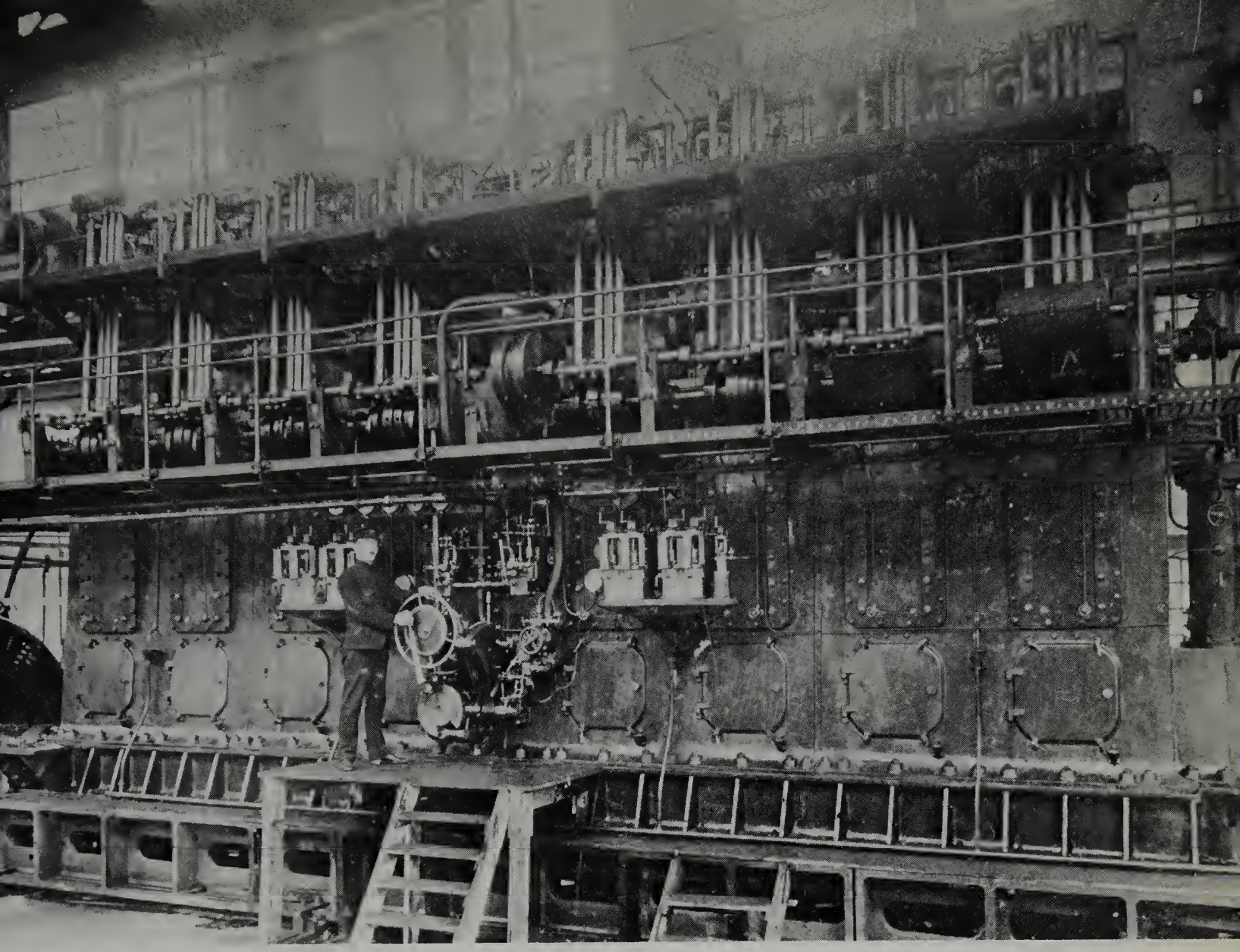
horsepower Swedish-built Atlas diesel used to power the *Fram* polar exploration ship which took Amundsen to the Antarctic in 1911, and it was in this same year that the Danish firm of Burmeister and Wain started to design and build the world's first ocean-going diesel-engined merchant ship.

This vessel, the twin-screw *Selandia,* was the first of three similar 7,400 ton ships ordered by the East Asiatic Company in 1910, two of which were to be built by Burmeister and Wain and the third by the British company, Barclay, Curle and Company, who were to build the diesel engines under licence from the Copenhagen firm. The *Selandia* and her sister ships each had two Burmeister and Wain eight cylinder four stroke diesel engines, giving a total power of 2,500 horsepower at 140 revolutions per minute, and a unique feature at that time was that the engines were reversible so that, as with steam ships, when the captain wanted to go astern the engine room staff could change the direction of rotation of the

The *Selandia*, launched in 1911 with two eight cylinder four stroke engines giving a total output of 2,500 horsepower.

engines within twenty seconds: with non-reversing diesel engines, gearing was required between the engine and the propeller for an astern manoeuvre.

This ability to make the diesel engine reversible had been the aim of diesel engineers all over the world for many years, but Burmeister and Wain—who are still among the world's foremost designers of large, high-power diesel engines for ship propulsion—were the first to achieve it successfully, and their success resulted from close cooperation between the company's technical director, Ivar Knudsen, and Rudolf Diesel over a period of ten years.



One of the *Selandia's* two main engines, built by Burmeister and Wain.

The funnel-less *Selandia* was launched on 4th November, 1911, started sea trials three months later, and commenced her maiden voyage to Bangkok via London on 12th February, 1912, returning to Copenhagen on 26th June. With a service speed of about 12 knots, she burned under ten tons of fuel oil per day, compared to the thirty or forty tons of coal that a steam ship of the same size and speed would have needed, and although some engine troubles were encountered on the voyage, the *Selandia* proved her worth and led the way to the world's current vast marine diesel industry. This famous ship remained in

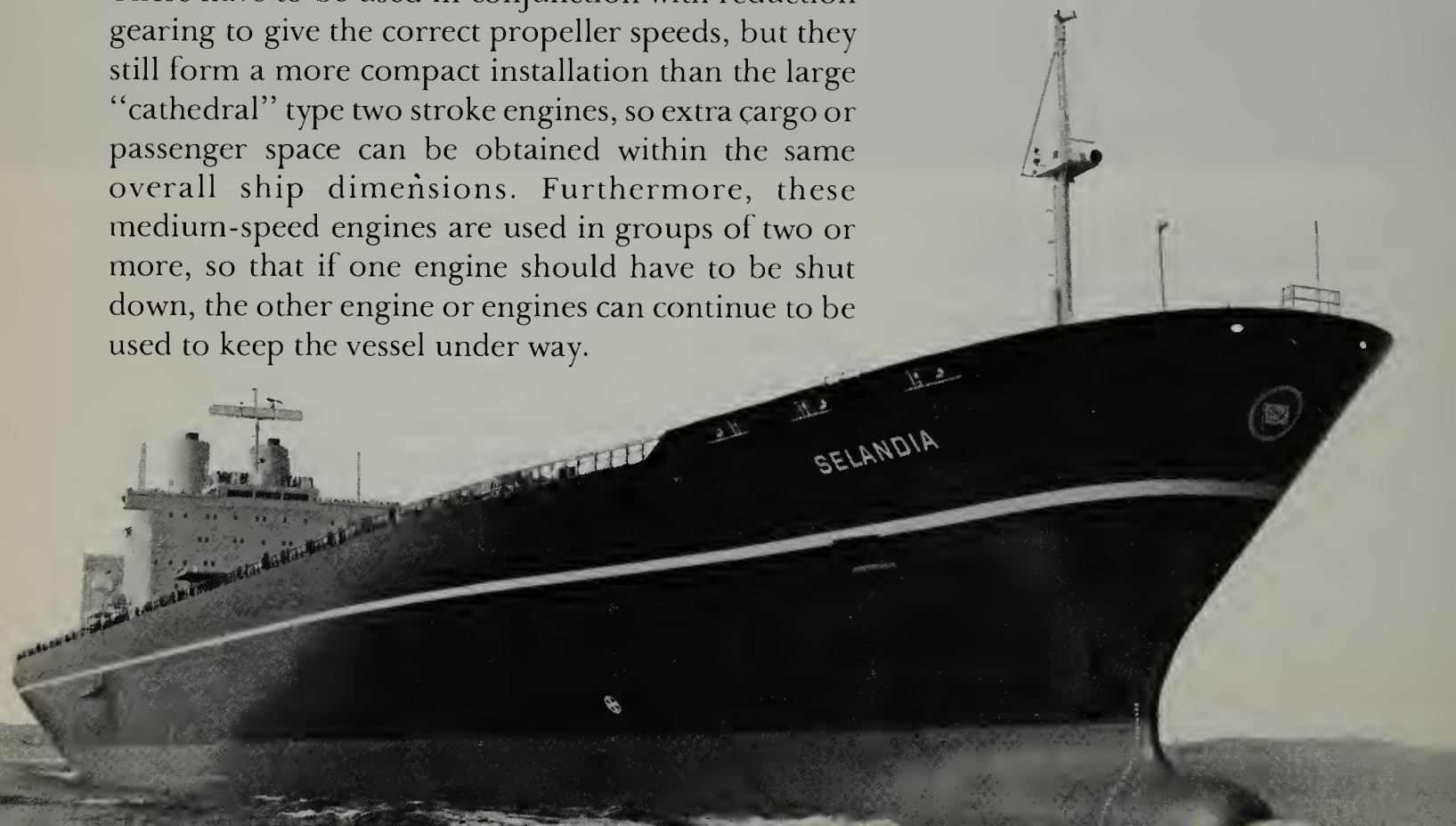
service until 26th January, 1942, when she ran aground off the coast of Japan, by which time she had changed owners several times and her name had become *Tornator*. But the name of *Selandia* lives on, and in 1972 Burmeister and Wain delivered another vessel of this name to the East Asiatic Company, this new *Selandia* being a container ship with three Burmeister and Wain diesels developing a total of seventy-five thousand horsepower.

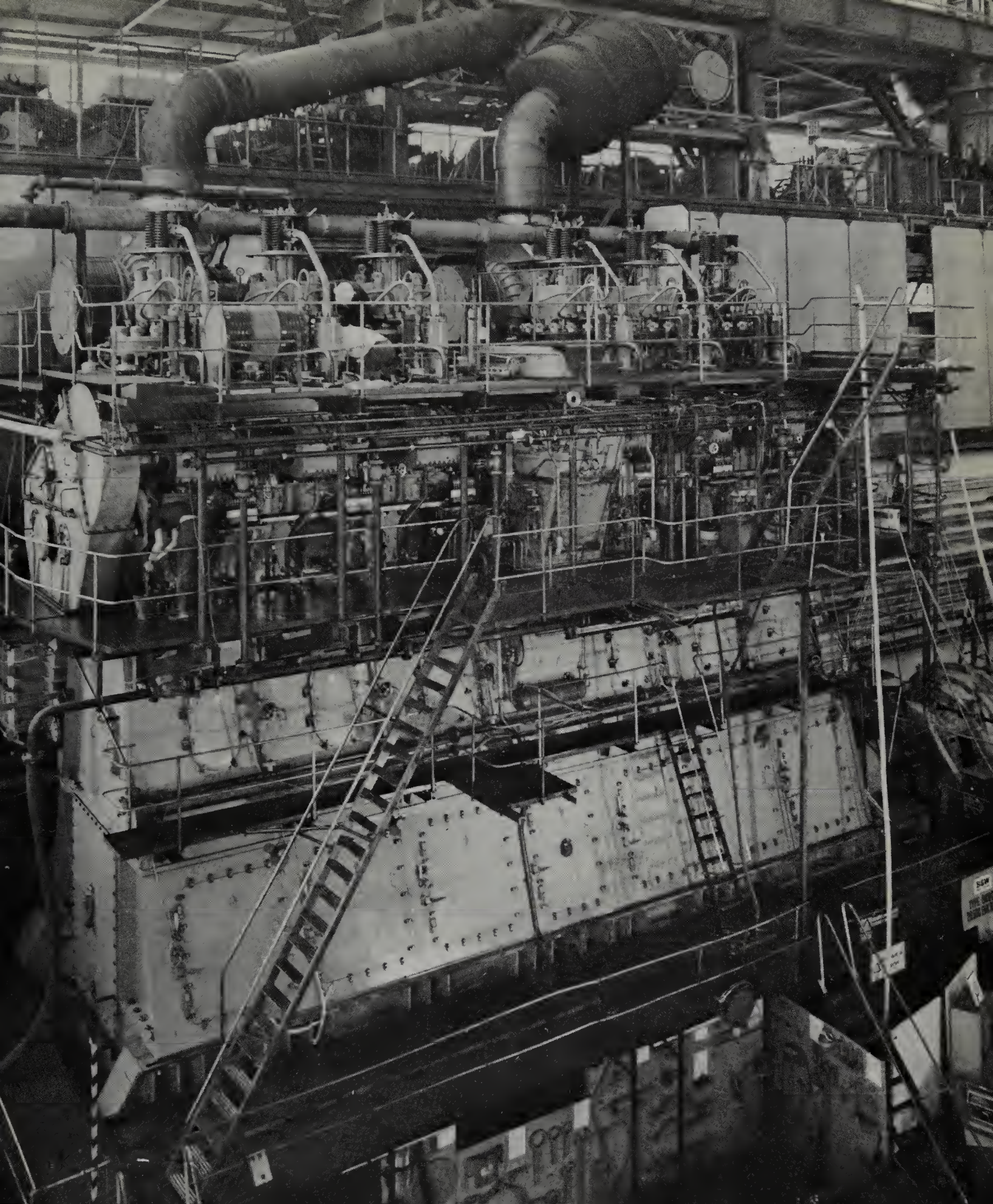
Since those early days, the diesel engine has proved supreme in the marine industry, and nowadays over seventy per cent of all merchant ships of over 300 tons deadweight have diesel propulsion, most of the remainder having steam turbines, and the proportion of diesel engines being fitted to new vessels is rising all the time.

Whereas until comparatively recently all large diesel-engined ships had slow-speed two stroke engines, of late compact medium-speed engines running five times as fast as the slow-speed types have been making considerable inroads into the market. These have to be used in conjunction with reduction gearing to give the correct propeller speeds, but they still form a more compact installation than the large "cathedral" type two stroke engines, so extra cargo or passenger space can be obtained within the same overall ship dimensions. Furthermore, these medium-speed engines are used in groups of two or more, so that if one engine should have to be shut down, the other engine or engines can continue to be used to keep the vessel under way.

Right One of the very latest Burmeister and Wain diesels, still on the test-bed in 1973 and rated at 20,500 horsepower. It is a six cylinder two stroke marine diesel engine with exhaust turbocharging.

Below The new *Selandia*, launched in 1972 and powered by three Burmeister and Wain diesels which together can develop a total of 75,000 horsepower.





BURLINGTON
9900
Burlington
Route

Top One of the first diesel locomotives in the world built in 1909 by Sulzer Brothers, directly driven by a two stroke engine.

Middle The *Burlington Zephyr*, U.S.A., 1934.

Bottom British Rail's prototype 125 miles per hour High Speed Train on a driver training run between Derby and Kettering in February, 1973. The train consists of two streamlined driving/power cars, each with a 2,250 horsepower diesel engine, and seven new passenger coaches.

However, for the really big ships, the large two stroke diesel will continue in use, since one single engine is capable of producing up to fifty thousand horsepower, whereas the present limit for medium-speed diesels is under thirty thousand horsepower, so a minimum of four engines would be required to give the same performance as two slow-speed two stroke units. Powers are always increasing, however, and the large-bore two stroke marine diesel capable of sixty thousand horsepower is already within sight, whilst eighteen-cylinder medium-speed engines giving up to two thousand horsepower per cylinder have been designed.

Another field in which the diesel engine has made tremendous inroads is that of rail traction. The world's first diesel locomotive was built in conjunction with the Swiss Sulzer concern in 1909, though Rudolf Diesel had envisaged this application for his brainchild many years before this. But final success came after Diesel's death, when diesel-electric locomotives were placed in service in north Germany in 1914.

The meteoric rise in usage of diesel power for rail traction started to gain momentum in the U.S.A. and in Europe before the 1939–45 war, but did not really become of great significance until the 1950s, and now there are very few steam locomotives left in service anywhere in the world. The diesel has electric traction as its main competitor, but electrification costs are high and services are brought to a halt if there is an electricity failure, so the diesel locomotive and railcar have the greater route flexibility and permanency of operation.

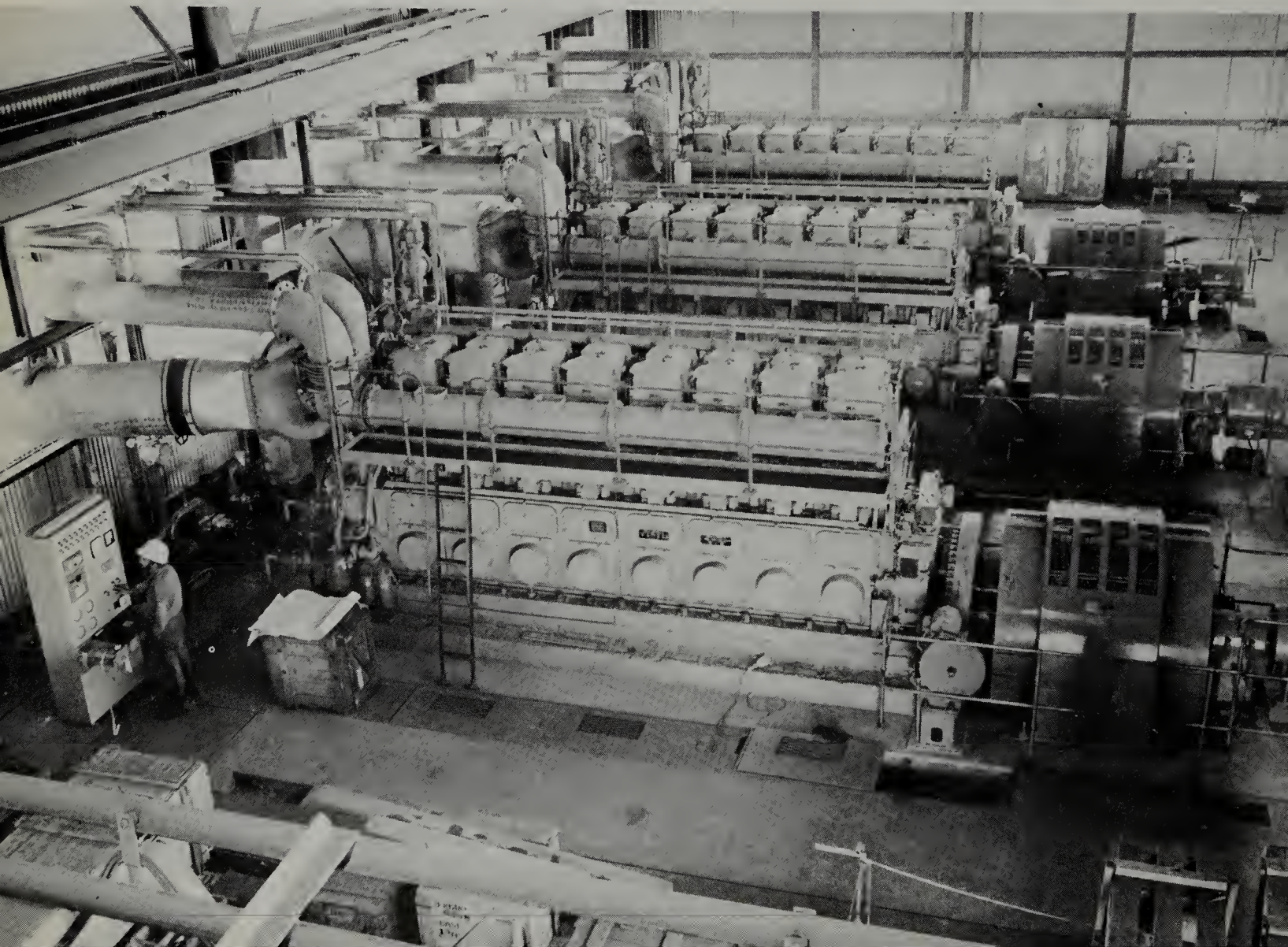
All sizes of diesel engine are used in industrial applications, ranging from engines of under five horsepower employed in driving small pieces of equipment on building sites and compact generating sets used as the main source of power on farms and the like, to huge slow-speed marine-type engines

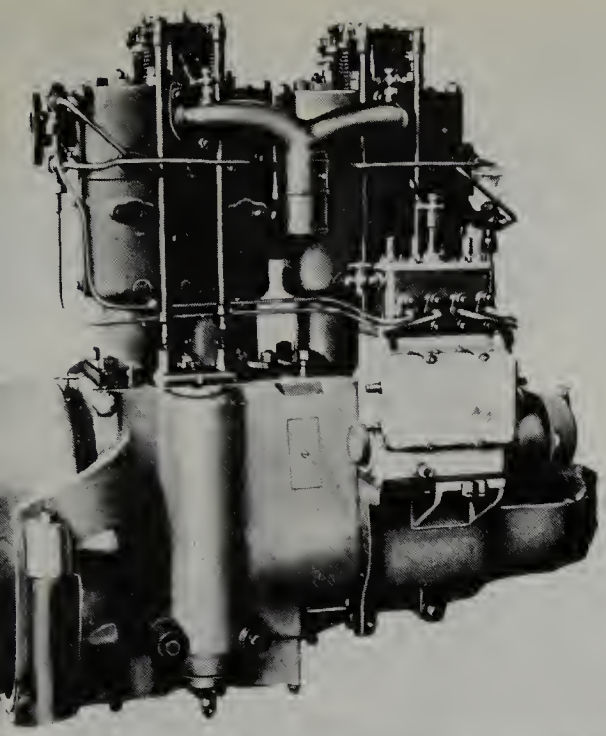
which provide all the electric power for complete towns. In densely populated areas, the diesel engine competes with the steam turbine for electricity generation, but it will often be found working alongside the steam turbine as a readily available engine to provide power to cope with sudden peak demands for electricity. Because the diesel engine's characteristics enable it to develop full power within a short time of its being started up, its value for these applications is considerable.

One of the largest single markets for the diesel engine these days is in road transport, and, shortly before his death in 1913, Rudolf Diesel had written: "I am still of the firm conviction that the automobile engine will come, and then I can consider my life's

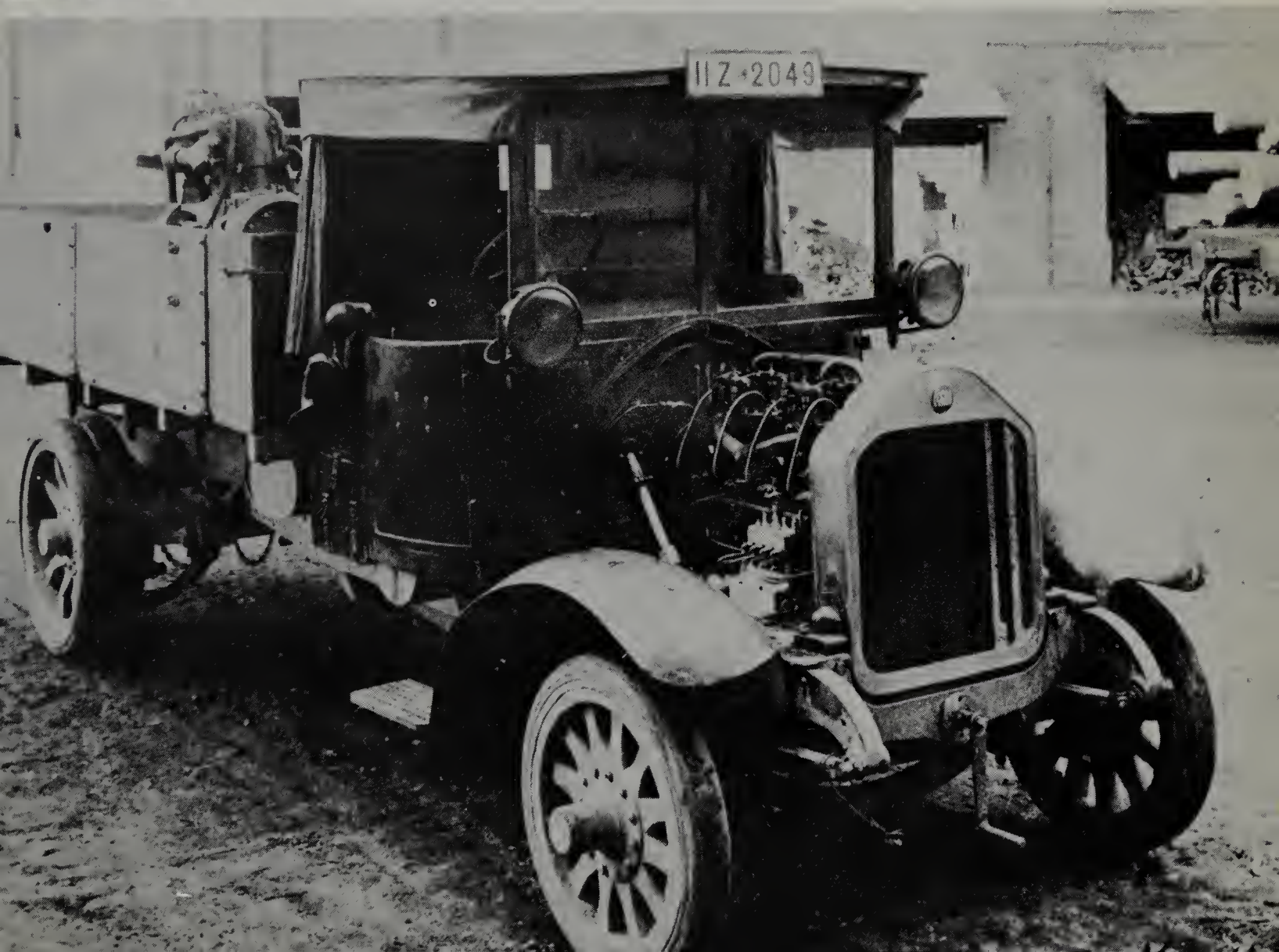
Opposite top The forty horsepower engine of the truck (*opposite below*) which M.A.N. claim to have been the world's first diesel-engined truck.

Below Diesels for generating electricity at an Australian mine. These three 3,000 horsepower Mirrlees engines provide power for, among other things, the large electric shovels used in mining at the Robe River Mine Site in Western Australia.

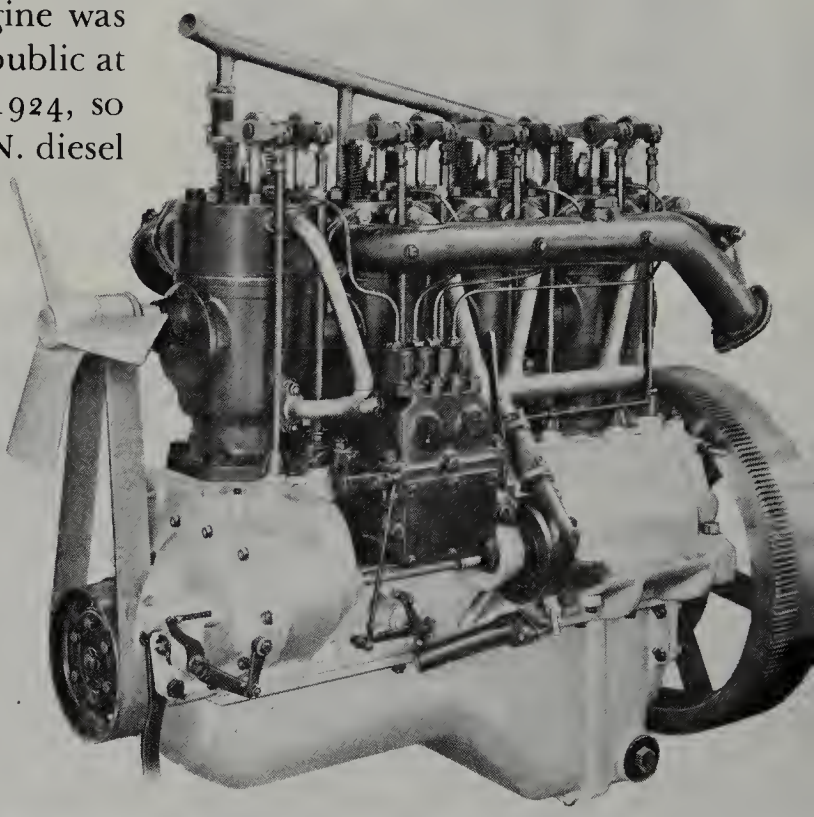




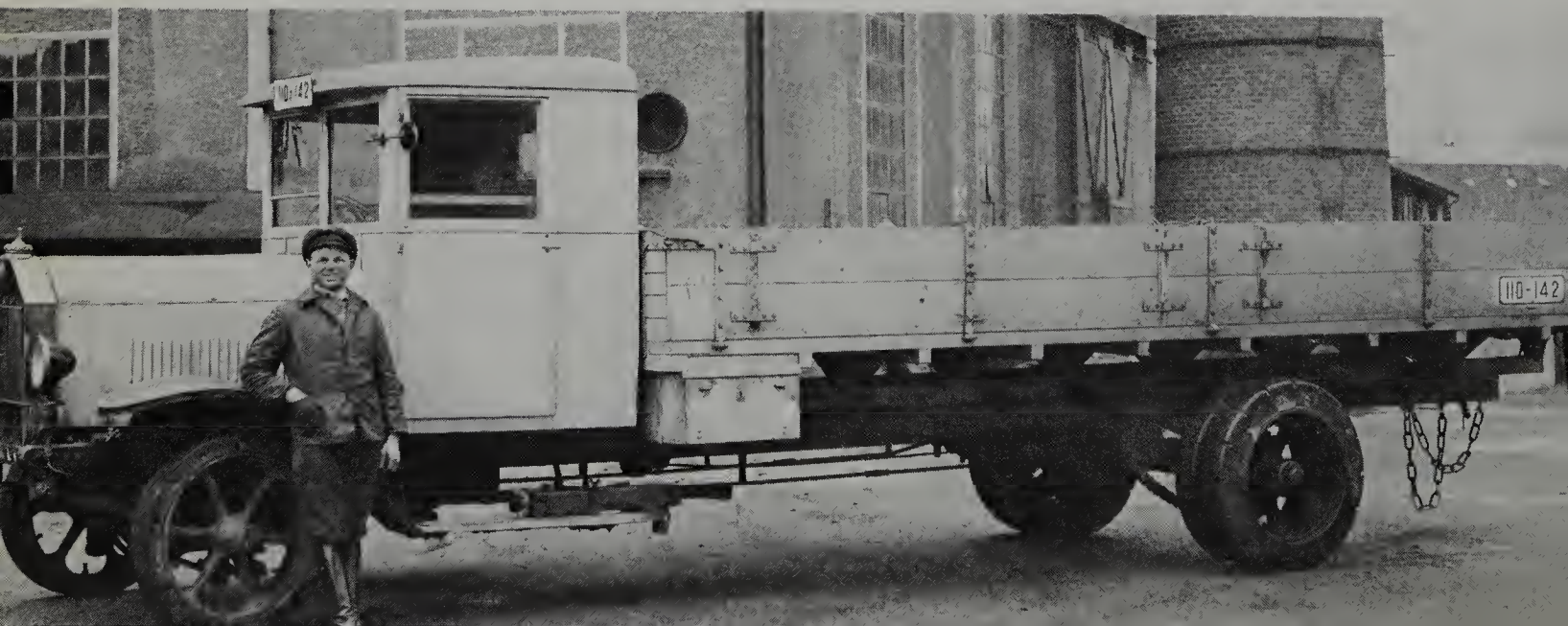
work ended." Yet the first successful diesel-engined road vehicles did not run until 1923, and it looks as though there will always be rivalry between the two German companies of M.A.N. and Daimler-Benz as to which one produced the world's first diesel-engined truck. M.A.N.'s diesel background goes right back to the first test carried out by Rudolf Diesel in Augsburg in 1893, and the first small, high-speed diesel engine developed by M.A.N. was built in 1923, this having solid fuel injection and developing forty horsepower at a crankshaft speed of nine hundred revolutions per minute. Installed in a five ton truck, a forty-five horsepower version of this engine was shown at the 1924 Berlin Motor Show in September, 1924.



Daimler-Benz's claim to the first diesel truck stems from the work that the original Benz company had been doing on diesel engines since 1907 in conjunction with Prosper l'Orange and later with the Swede Harry Leissner. In 1922, Benz commenced production of a thirty horsepower twin cylinder diesel engine for use in ploughing tractors, and the following year a four cylinder version of this engine was built which developed fifty horsepower at one thousand revolutions per minute. This engine was fitted into a five ton truck and exhibited in public at the Amsterdam Motor Show in February, 1924, so beating the first public showing of the M.A.N. diesel vehicle by seven months.

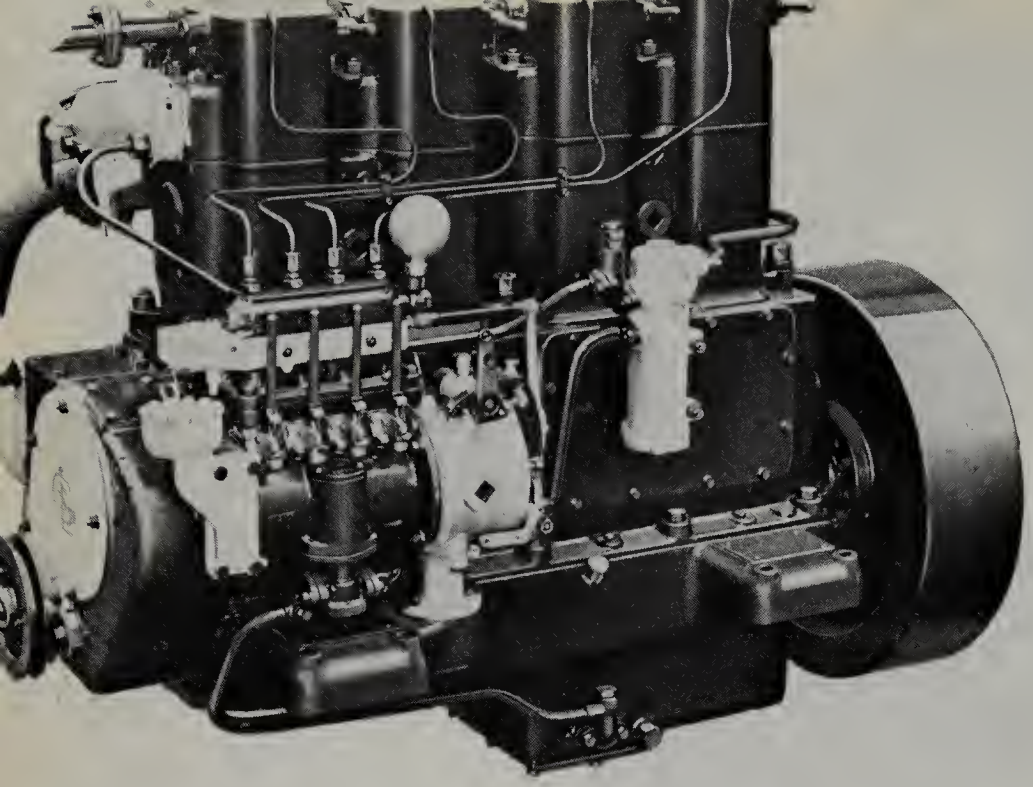


Right The forty-five horsepower engine and *below* the truck into which it fitted which according to Daimler–Benz was really the world's first diesel truck. It beat M.A.N.'s truck to a public showing by seven months.



The American Clessie Cummins in one of his record breaking diesel-engined cars.

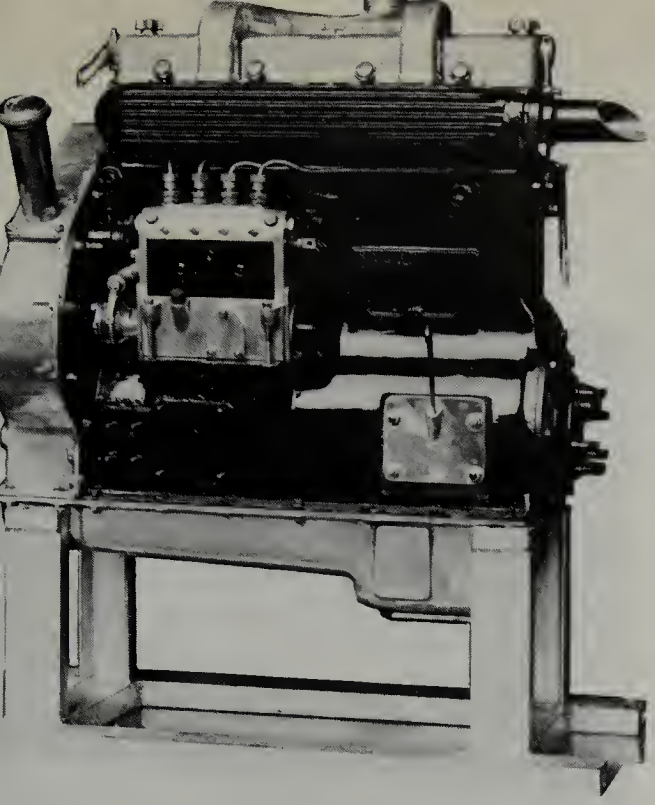
Brief mention must here be made of two independent pioneers in the field of vehicle diesel engines. One of these was the American, Clessie Cummins, who started building diesel engines under the Dutch Hvid licence in 1919, and who applied a marine version of a later development of these engines to an old Packard car in 1929, and subsequently carried out some record breaking runs in diesel-engined cars, trucks and buses to publicize his engine designs.



Right A 1933 Perkins Fox diesel engine. Frank Perkins drove from Peterborough to Perth with this engine fitted into a small Hillman car at a running cost of $\frac{1}{8}$ (old) penny per mile.

Left A Gardner engine first built in 1929/30 capable of developing up to 52 horsepower. It is a four stroke four cylinder direct injection diesel engine.

Below A *Lancia* bus, the first British bus to be converted from petrol to diesel power. A Gardner 4L2 engine (*left*) was installed early in 1930 and the bus went into service that March.



Another pioneer in the field of vehicle diesel engines was Frank Perkins, an Englishman who built his first diesel engine in 1933 and thereby started a company which now builds about 400,000 diesel engines a year for vehicle, agricultural, marine and industrial applications. It was Frank Perkins' company that brought the low cost high-speed diesel engine to the mass market by making this type of diesel engine generally available to car, truck and bus manufacturers who had not the resources to build their own engines. In the same breath, of course, one must mention Gardner, who fitted one of their marine diesel engines to a British bus in 1930, and who the following year introduced a range of vehicle diesels that has remained successful and very little changed in basic design to this very day.

A modern British Leyland Scammell diesel-engined truck.

Postscript

"Si monumentum requiris, circumspice." These famous words of Latin, which translated mean: "If you seek his monument, look around you," can be found on a wall in the crypt of Saint Paul's Cathedral, in London, and they refer to the architect of this most famous of cathedrals, Sir Christopher Wren, who lies buried beneath a simple marble slab in the crypt.

Rudolf Christian Karl Diesel has no known grave. Just a simple carved piece of rock in the Rudolf Diesel Memorial Grove in Augsburg, Germany, and the magnificent museum in the M.A.N. factory in the same town, exist as a direct memorial to one of the finest—and saddest—engineers the world has known.

But Sir Christopher Wren's epitaph is equally apposite with regard to Rudolf Diesel, because even when we cannot actually see a diesel engine near to us, we know that many are working for us at that very moment—transporting goods and people, helping to make those things that we rely on as part of our modern civilization, contributing to our well-being, our food, our light, our heat, our entertainment, our health.

Rudolf Diesel brought into the world a power source that has since become indispensable—and is certain to remain so in all our lifetimes at least. His perseverance in the face of practical difficulties and almost crippling criticism enabled him to achieve many of his objectives and to prove to the world that his principles and theories were right. Had his personal life been happier, he would have lived to see "his engine" used to an extent that was beyond even his wildest dreams.

The Memorial in the Rudolf Diesel Memorial Grove in Augsburg. This memorial was presented in 1957 by the Yanmar Diesel Engine Company of Japan. The inscription reads, "Immortal is your spirit in far off Japan."

Date Chart

B.C. 130	Hero of Alexandria builds his aeolipile "steam turbine."
1654	Otto van Guericke conducts his vacuum-power experiments.
1673	Christian Huygens builds his gun-powder engine.
1688	Denis Papin builds a steam-powered atmospheric engine.
1695 (ca)	Thomas Savery builds steam pumping engine based on Papin type.
1712	Thomas Newcomen commences production of steam pumping engines.
1759	James Watt designs double-acting condensing steam engine.
1765	Nicholas Joseph Cugnot builds model steam-driven artillery tractor.
1770	Cugnot's full size tractor runs on the road under its own power.
1804	Richard Trevithick builds world's first steam locomotive.
1807	Robert Fulton's paddle steamer operates in America.
1812	American *Savannah* sailing ship crosses Atlantic with steam auxiliary power.
1816	Robert Stirling patents hot-air engine in Scotland.
1826	Samuel Brown builds gas-engined road carriage.
1838	William Barnett patents series of gas-fuelled internal combustion engines.
1858	Rudolf Christian Karl Diesel born in Paris on 18th March.
1860	Jean Joseph Etienne Lenoir starts to build gas engines.

1862	Alphonse Beau de Rochas originates four stroke internal combustion cycle.
1862	Nikolaus August Otto's first four stroke gas engine runs.
1862	Lenoir applies his gas engine to road carriage.
1864	Otto joins with Eugen Langen to form world's first internal combustion engine factory.
1875	Siegfried Markus of Mecklenburg builds successful gas-engined road vehicle.
1876	Otto builds first prototype four stroke gas engine.
1882	Karl Benz patents small two stroke petrol engine.
1883	Gottlieb Daimler and Wilhelm Maybach build high-speed hot-tube petrol engine.
1884	Otto perfects spark-ignition four stroke petrol engine.
1885	Priestman brothers build first successful oil engine in England.
1885	Benz applies his petrol engine to a bicycle.
1886	Benz builds a three wheeled car and Daimler builds a four wheeler.
1890	Herbert Akroyd Stuart patents compression-ignition oil engine.
1892	Richard Hornsby & Sons Ltd. start production of Akroyd Stuart's compression-ignition engine.
1892	Rudolf Diesel's first patent for a high-compression heat engine applied for in Germany (27th February).
1893	First tests of Diesel's engine begin in Augsburg.
1893	Diesel is granted second patent for a more practical heat engine.
1894	Diesel's modified prototype engine runs briefly under its own power.

1897	Successful tests of Diesel's engine carried out in Augsburg.
1897	First diesel engine built in Great Britain by Mirrlees, Watson & Yaryan Co. Ltd. of Glasgow.
1898	First engine built to Diesel's design enters service in Germany.
1898	First American-built diesel placed in service by Adolphus Busch.
1902	Four 400 horsepower diesel engines supplied by M.A.N. for power station in Kiev, Russia.
1902	Diesel engine applied to canal barge in France.
1903	French company builds two reversible diesel engines for submarine use.
1908	Two old steamships repowered with diesel engines in Holland.
1909	Rudolf Diesel begins trials with locomotive engine.
1910	Rudolf Diesel builds small engine intended for vehicle use.
1911	Dr. A. J. Büchi starts experiments with exhaust-driven supercharging.
1911	Diesel-engined *Fram* takes Amundsen to Antartic.
1912	Maiden voyage of *Selandia,* world's first diesel-powered ocean-going ship.
1913	Rudolf Diesel disappears at sea, night of 29th/30th September.
1914	Diesel-engined locomotives enter service in north Germany.
1923	Daimler-Benz and M.A.N. separately build successful diesel-engined trucks.
1924	Sulzer diesel-electric rail cars enter service in Switzerland.
1929	Aircraft powered by Junkers diesel engine flies.
1934	*Pioneer Zephyr* streamlined diesel train

	enters service in U.S.A.
1934	Daimler-Benz build diesel engines for airships *Graf Zeppelin* and *Hindenburg*.
1935	Daimler-Benz start production of diesel-engined passenger cars.
1937	Dornier flying boats with Junkers diesel engines start regular services between Europe and South America.
1954	Turbocharged diesel trucks are put into production in Sweden by Volvo.

Further Reading

Bell, P. C., *Mechanical Prime Movers* (Macmillan, 1971)

Clark, G. H., *Marine Diesel Lubrication* (Burmah–Castrol Marine, 1970)

Compiled, *BICEMA Catalogue* (British Internal Combustion Manufacturers' Association, 1972)

Compiled, *Diesel & Gas Turbine Worldwide Catalog* (Diesel Engines Inc., annual)

Diesel, E., Goldbeck, G. & Schildberger, F., *From Engines to Autos* (Regnery, 1960)

Judge, A. W., *High Speed Diesel Engines* (Chapman & Hall, 1966)

Pounder, C. C., *Diesel Engine Principles & Practice* (Newnes–Butterworth, 1962)

Seale, J. N., *Questions & Answers on Diesel Engines* (Newnes–Butterworth, 1965)

Williams, D. S. D., *The Modern Diesel* (Newnes–Butterworth, 1972)

Glossary

AIR-BLAST INJECTION Method used in early diesel engines to force the fuel into the cylinder against the high pressure of air already present in the cylinder, the fuel being driven into the cylinder by air at higher pressure than that in the cylinder.

BRAKE HORSEPOWER See "Power."

CARNOT CYCLE Theoretical ideal working cycle for a heat engine, proposed by Sadi Carnot in the early nineteenth century but later shown to be impossible to achieve as it made no allowances for frictional and heat losses.

COMBUSTION CHAMBER Space formed in the piston top (crown), or in the cylinder head, where the fuel is burned to produce the working pressure.

COMPRESSION PRESSURE Maximum pressure reached inside a cylinder with the piston at the end of its compression stroke but before the fuel charge is ignited.

CRANKSHAFT The main shaft of an engine which is cranked to take the connecting rods from each piston and convert the vertical motion of the pistons into rotary motion.

CROSSHEAD Connection between the piston rod and the connecting rod in very large slow-speed diesel engines. In medium- and high-speed engines, the connecting rod is joined directly to the piston without the use of a piston rod, and this type of engine is known as a "trunk piston" engine.

CYLINDER Accurately bored tube in which a piston can slide. Cylinders can be formed separately or they can be side by side in a single large casting called the "cylinder block."

CYLINDER HEAD The end cover of a cylinder or cylinder block which also contains the valves.

DIESEL ENGINE An internal combustion engine in which the fuel is ignited as a result of being injected into air in the cylinder which has been compressed and is therefore at a high enough temperature to cause the injected fuel to burn spontaneously. The high compression pressure gives greater thermal efficiency (q.v.), so the diesel engine is more economical on fuel than any other type of engine. It is sometimes referred to as an "oil engine" or a "compression-ignition engine."

DIRECT INJECTION Fuel is injected directly into the combustion chamber formed in the piston crown, giving better fuel consumption and easier starting at low temperatures. This is sometimes referred to as the "open" combustion system. (See also "Indirect injection.")

DOUBLE ACTING An engine in which the expanding gas pushes on both sides of the piston in turn so that each stroke is a working stroke.

DUAL-FUEL ENGINE A diesel-type engine that can run either on gaseous fuel with a small amount of liquid fuel, or on liquid fuel alone.

FOUR STROKE CYCLE The four stroke cycle gives one working stroke in each cylinder for every two revolutions of the crankshaft. The three other strokes are concerned with filling the cylinder with air, compressing that air and, after the working stroke, ridding the cylinder of spent exhaust gases.

GAS ENGINE An engine that uses only gaseous fuel, which can be manufactured, or a natural gas.

GAS TURBINE A rotary form of internal combustion engine. As used in jet aircraft the driving force comes from the direct reaction of the exhaust gases pushing on the engine. In some propeller-driven aircraft and in engines used on sea or land, however, the exhaust gas is used to drive a power turbine to turn a shaft.

HORSEPOWER See "Power."

INDIRECT INJECTION This takes various forms in

modern diesel engines, but basically it is the alternative to "direct injection" (q.v.). It involves the use of a "pre-combustion principle" in which the fuel in initially ignited in an ante-chamber connected to the cylinder space by a throat or holes. With indirect injection the engine can work at higher speeds and produce less pollution, but more fuel is used and cold starting is not as good as with direct injection.

MECHANICAL EFFICIENCY Some of the work that an engine does goes towards overcoming friction inside the engine. The smaller the amount of work needed to overcome that friction compared with the total amount of work available from the engine, the greater is the mechanical efficiency of that engine.

PETROL ENGINE An internal combustion engine in which a mixture of air and petrol vapour is let into the cylinder and then ignited with an electric spark.

PISTON A circular block of metal which is accurately made to fit the cylinder so that it can slide in the cylinder easily yet at the same time form a seal in the cylinder to prevent gases escaping between the sides of the piston and the walls of the cylinder. In this way the expanding hot gases can push the piston along the cylinder, and this power can be converted into rotary motion by linking the piston to a revolving crankshaft with a connecting rod.

POWER This is the rate of work of an engine, normally expressed either in terms of brake horsepower (bhp), or in kilowatts (kW). Because horsepower depends on the engine's speed of rotation, this is usually given as well. E.g. 1,000 bhp (or 746 kW) at 750 rev/min (revolutions per minute).

PRESSURE CHARGING This is a way of increasing the mass of air admitted to the cylinder by raising the pressure of the air to above atmospheric. In this way, more fuel can be burnt and more power ob-

tained. Pressure charging is usually achieved in modern diesel engines by using an exhaust-driven "turbocharger," although some engines, especially high-speed two stroke diesels, are fitted with mechanically-driven "superchargers."

RECIPROCATING An engine containing pistons that move backward and forward inside cylinders is described as a reciprocating engine. Engines such as turbines and Wankel-type designs, which are rotary types, contain no reciprocating parts.

STEAM ENGINE An external combustion engine driven by steam from a separate boiler. The steam is let into the cylinder (in the case of reciprocating engines) or into the turbine casing (in the case of a steam turbine) and forces the piston up and down, or the turbine rotor round. Thermal efficiency is not as high as that of a diesel engine, and reciprocating steam engines are rarely used nowadays, whilst steam turbines are mainly used only where very high powers are required for use at sea or in electricity generation.

THERMAL EFFICIENCY This is the percentage of the total heat energy in a fuel that can be converted by an engine into useful work. Modern diesel engines can give thermal efficiencies of over 40 per cent, which is up to double that of a petrol engine or gas turbine engine and some 50 per cent higher than a conventional steam turbine. The higher the thermal efficiency, the smaller the amount of fuel that is needed for an engine to do the same amount of work.

TORQUE This is the twisting force produced when the crankshaft turns.

TRUNK PISTON See "Crosshead."

TURBINE A rotor assembly with blades on the outside. When a high pressure liquid or gas acts on the blades, the rotor turns and produces power.

TURBOCHARGER See "Pressure charging."

TWO STROKE The two stroke cycle gives one working

stroke per cylinder for each revolution of the crankshaft. Except for one or two manufacturers of medium-and high-speed diesels, the two stroke cycle is nowadays used only for large-bore slow-speed engines suitable for high-powered use at sea or in industry.

WATER JACKET These are hollow chambers formed around an engine's cylinder and cylinder head through which water is circulated to remove heat from inside the engine to prevent overheating. The cooling water is also circulated through a radiator or other device to lower the water's temperature before it is returned to the water jacket.

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